

POWER SYSTEM PROTECTION & CONTROL

STAGE 3A-PSP104

TEXTBOOK/WORKBOOK

POWER SYSTEM PROTECTION & CONTROL

STAGE 3A-PSP104

TEXTBOOK/WORKBOOK

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POWER SYSTEM PROTECTION & CONTROL

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COURSE OVERVIEW

OVERVIEW

After completion of this course, the trainee will have the necessary knowledge and skills to identify the different types of bus bar protection. The course also scopes out the commissioning and testing of the protective relays.

Static relays are also included in this course, starting with the relay components, basic circuits, and the static relay applications provided with practical tasks for different types of static relays.

OBJECTIVES

Upon completion of this course, the trainees will be able to:

- List the components of overall protection of bus bars.
- Explain the protective relay testing and commissioning.
- Classify the electrical diagrams of control devices.
- Define the in-service test of protective relays.
- Explain the theory and operation of static relays.
- List the main components of static relays.
- Identify the applications of static relays.

CONTENTS

The contents of the (3A) course material are divided into three (3) units of instructions with nine (9) lessons.

Supplementary additional handout drawing is given to complete the electrical diagrams of control circuits.

Text and workshop material

Unit 1	Bus Bar Protection
Unit 2	Relay Testing & Commissioning
Unit 3	Static Relays

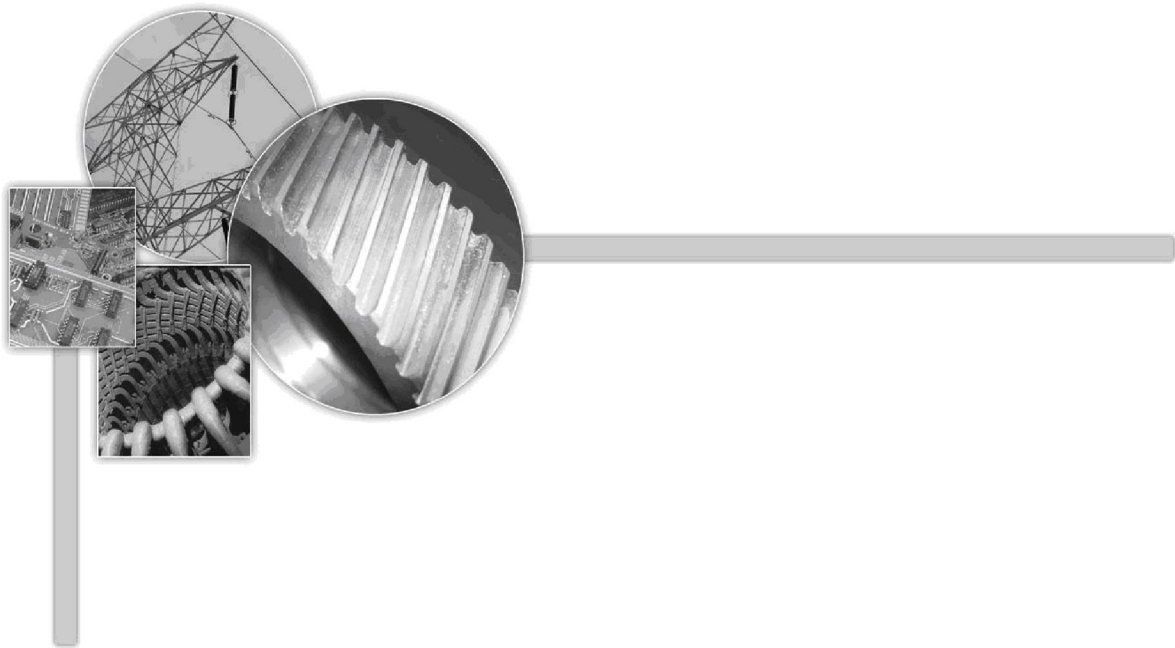
DURATION

This course is for duration of nine (9) weeks to cover theoretical part, practical tasks, and field visits.

**POWER SYSTEM PROTECTION & CONTROL
STAGE 3A-PSP104**

**PACING SCHEDULE
TEXTBOOK/WORKBOOK**

<u>Unit</u>	<u>Description</u>	<u>Duration</u> <u>(Hours)</u>
<u>1</u>	Bus Bar Protection	50
<u>2</u>	Relay Testing & Commissioning	50
<u>3</u>	Static Relays	100
	TOTAL	200



UNIT 1

BUS BAR PROTECTION

UNIT-1

BUS BAR PROTECTION

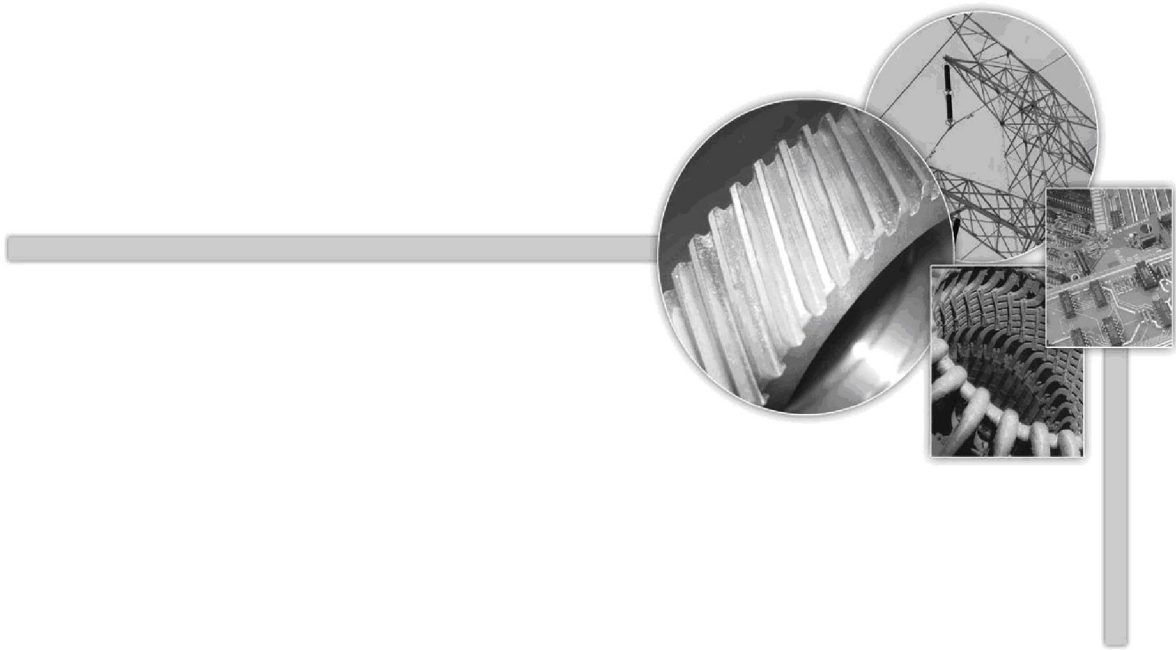
OVERVIEW

This unit discusses the types of bus bar arrangements, faults and the overall protection schemes of bus bar. The unit also scopes out the bus bar protection by differential relays, and using high impedance of differential relays.

OBJECTIVES

Upon completion of this unit, the trainee will be able to:

- Classify the types of bus bar arrangements.
- Define the overall protection of bus bars.
- Explain bus differential protection.
- Define high impedance differential schemes.



LESSON 1.1

OVERALL PROTECTION OF BUS BAR

LESSON 1.1

OVERALL PROTECTION OF BUS BAR

OVERVIEW

This lesson discusses the types of bus bar arrangements, bus bar faults, and overall protection schemes of bus bars.

OBJECTIVES

Upon completion of this lesson, the trainee will be able to:

- Identify the types of bus bar arrangements.
- Demonstrate bus bar faults and its causes.
- Describe ground fault bus protection.
- Describe the directional comparison schemes.

INTRODUCTION

The protection scheme for a power system should cover the whole system against all probable types of fault. Unrestricted forms of line protection, such as overcurrent and distance systems, meet this requirement, although faults in the bus bar zone are cleared only after some time delay. If a unit protection is applied to feeders and plant, the bus bars are not inherently protected. Bus bars may be left without specific protection, for one or more of the following reasons:

- a. The bus bars and switchgear have a high degree of reliability, to the regarded point as intrinsically safe.
- b. It was feared that accidental operation of bus bar protection might cause widespread dislocation of the power system, which, if not quickly cleared, would cause more loss than would the very infrequent actual bus faults
- c. It was hoped that system protection or back-up protection would provide sufficient bus protection if needed.



Fig. 1.1-1 69kV Bus Bar in Substation

It is true that the risk of a fault occurring on metal-clad gear is very small, but it cannot be ignored. However, the damage resulting from one unclear fault, because of the concentration of fault MVA may be very extensive indeed, up to the complete loss of the station by fire. Serious damage to or destruction of the installation would probably result in widespread and prolonged supply interruption.

Finally, system protection will frequently not provide the cover required. Such protection may be good enough for small distribution substations, but not for important stations. Even if distance protection is applied to all feeders, the bus bar will lie in the second zone of all the distance protections, so a bus fault will be cleared relatively delayed, and the resultant duration of the voltage dip imposed on the rest of the system may not be tolerable.

With outdoor switchgear the case is less clear since, although the likelihood of a fault is higher, the risk of widespread damage resulting is much less. In general then, bus bar protection is required when the system protection does not cover the bus bars, or when, in order to maintain power system stability, high-speed fault clearance is necessary. Unit bus bar protection provides this, with the further advantage that if the bus bars are sectionalized, one section only need be isolated to clear a fault. The case for unit bus bar protection is in fact strongest when there are bus sections.

BUSBAR FAULTS

The majority of bus faults involve one phase and earth, but faults arise from many causes and a significant number are inter-phase clear of earth. In fact, a large proportion of bus bar faults result from human error rather than the failure of switchgear components.

With fully phase-segregated metal-clad gear, only earth faults are possible, and a protection scheme need have earth fault sensitivity only. In other cases, an ability to respond to phase faults clear of earth is an advantage, although the phase fault sensitivity need not be very high.

SINGLE BUS

The simplest Bus arrangement is the single Bus, as shown in Fig. 1.1-2. The protected area is defined by the location of the CTs. The inboard CT on each breaker is used for protection of the connected circuit. The CTs are usually located in the circuit breaker Bushings. To simplify the diagrams, the breaker disconnects are shown in the closed position, unless they are normally open.

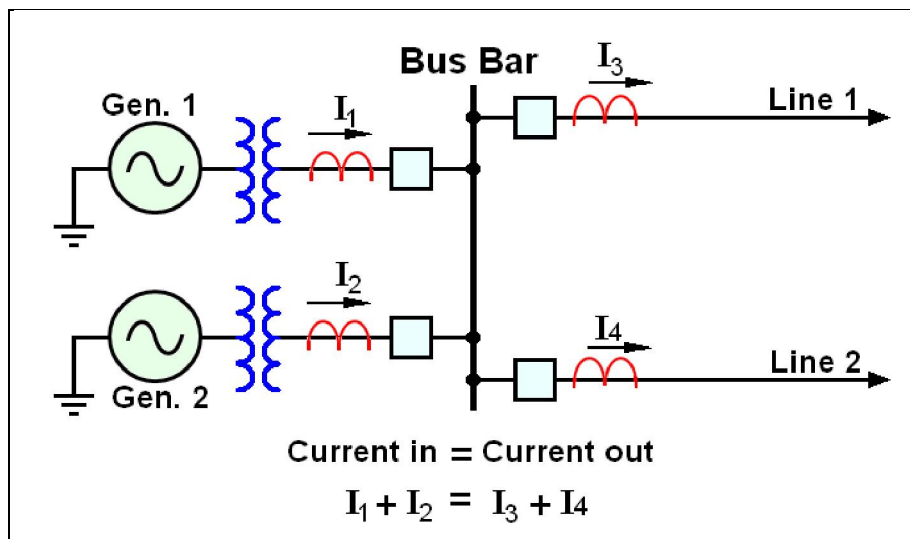


Fig. 1.1-2 Single Bus Arrangement

SPLIT BUS WITH TIE BREAKER

In order to improve reliability, the Bus is sometimes split with a Tie Breaker, connecting the two halves, as shown in Fig. 1.1-3. In this arrangement, the Tie Breaker will normally be closed in order to increase system reliability. Each side of the Bus, including the Tie Breaker, is protected by separate relays providing two separate zones of protection.

A fault occurring on Bus-B would cause the connected circuit breakers, including the Tie Breaker, to open and isolate the faulty half of the Bus leaving the remaining section of Bus-A to operate intact.

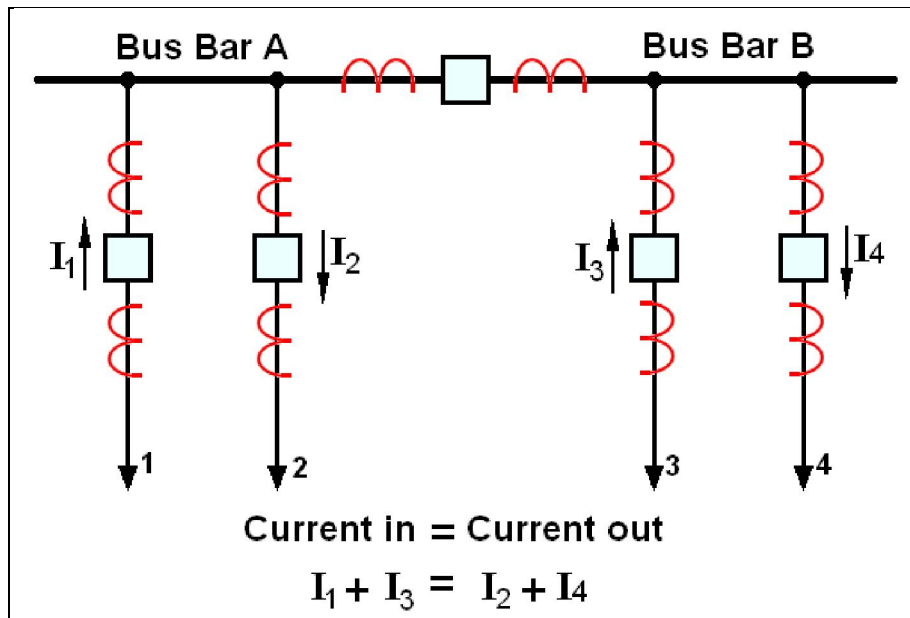


Fig. 1.1-3 Split Bus with Tie Breaker

When there is only one circuit breaker in each circuit and breaker needs to be isolated for maintenance, the line has to be taken out of service. One economical way of getting around this problem is to provide a Transfer Bus.

TRANSFER BUS

As shown in Fig. 1.1-4, the circuit disconnects are so arranged that any particular line can feed into either the main Bus through the circuit breaker or directly into the Transfer Bus. If we need to isolate Circuit Breaker 1 for maintenance, the line 1 disconnect will be connected to the Transfer Bus and the Tie Breaker would now operate as the breaker for that line.

While in this configuration, the Transfer Bus acts as part of the line and is thus protected by the line protection. The inboard CT of the Bus Tie-Breaker becomes part of the line protection. This may create a problem where different protection settings are required for different transmission lines. There is always the possibility of forgetting to make the change or perhaps make incorrect settings.

Only the main Bus is controlled by differential protection including the outboard CT of the Bus tie.

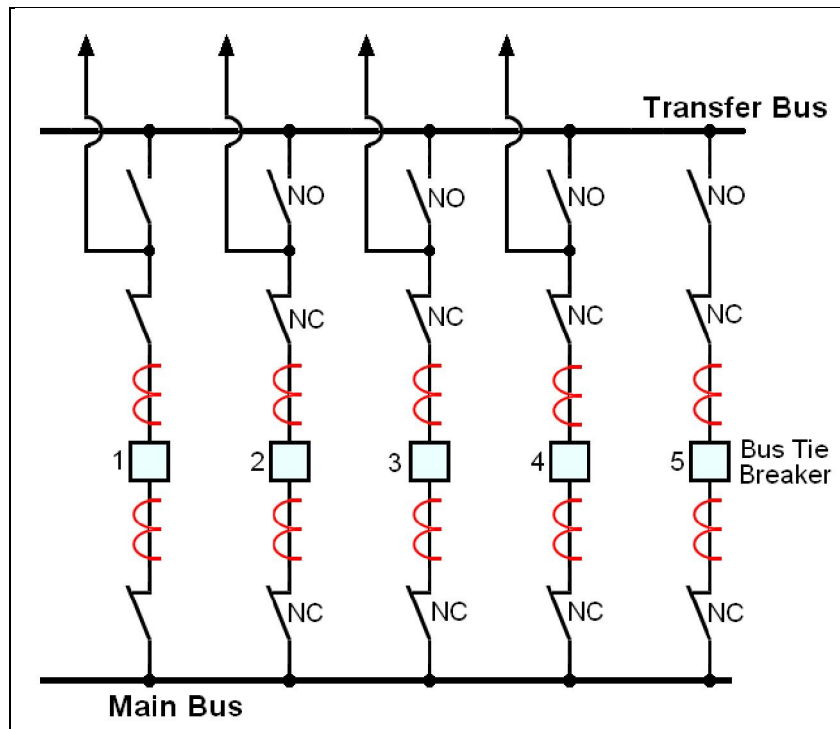


Fig. 1.1-4 Transfer Bus

DOUBLE BUS SINGLE BREAKER

A Double bus single breaker arrangement is shown in Fig. 1.1-5 where each circuit can be connected to either Bus-A or Bus-B according to the selection of the circuit disconnects and each Bus is provided with differential protection, separately.

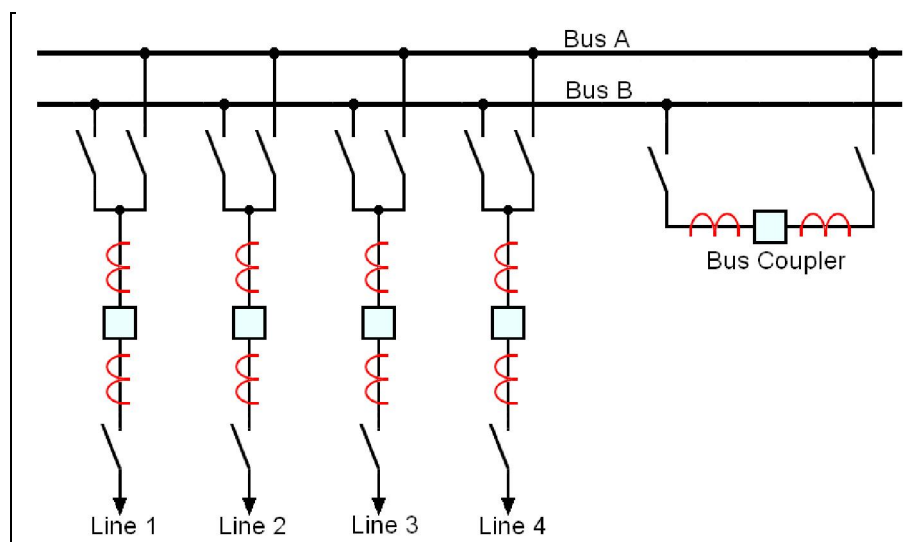


Fig. 1.1-5 Double Bus Single Breaker

There is another configuration that uses Bypass Disconnect Switch around each circuit breaker, as shown in Fig. 1.1-6. This configuration allows us to remove a breaker from service without interruption. Fig. 1.1-6 shows the arrangement with breaker 1 out of service and Bus-A functioning as the transfer Bus. Before closing the transfer breaker, differential protection on both Buses must be disabled since closing the transfer breaker unbalances differential protection on the Buses.

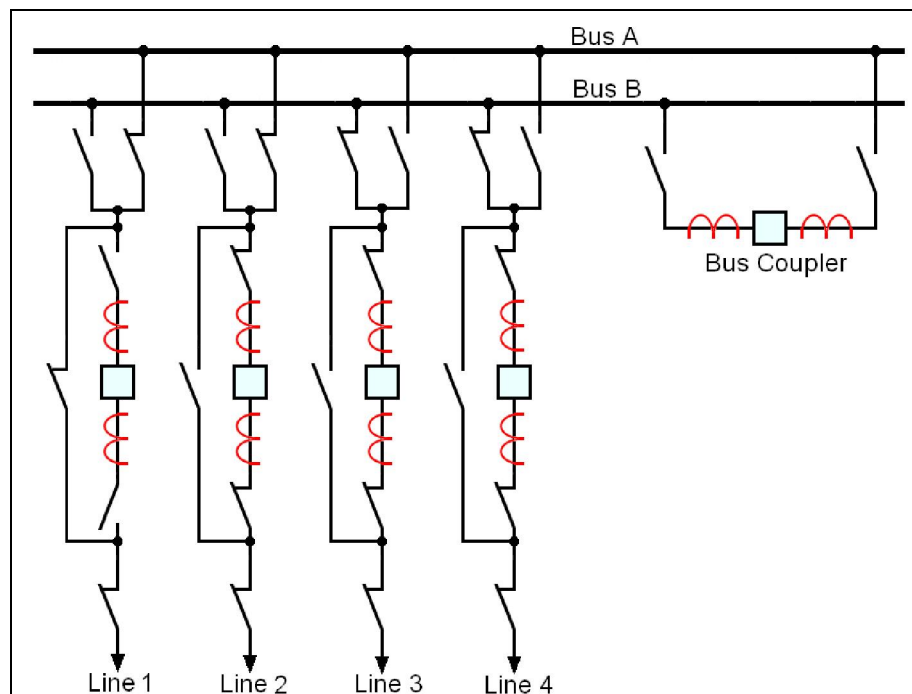


Fig. 1.1-6 Double Bus Single Breaker-Bus A functioning as Transfer Bus

DOUBLE BUS DOUBLE BREAKER

Where the greatest flexibility is required on an important substation, a Double Bus Double Breaker arrangement is used, as shown in Fig. 1-7. Each incoming circuit has two circuit breakers, thus allowing it to be immediately connected to either Bus-A or Bus-B. Each Bus has its own differential zone of protection. A fault occurring on Bus-A will trip all of the breakers connected to that Bus and immediately the other breakers connect these circuits to Bus-B.

With this arrangement it is necessary to provide two CTs for line protection, one on each alternate breaker connected in parallel. The VTs are connected one to each line.

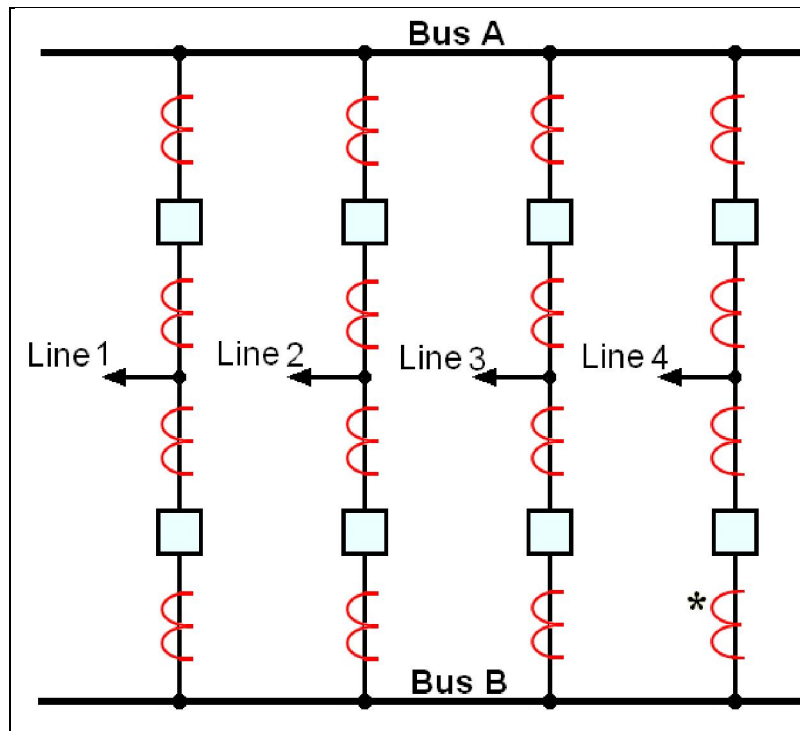


Fig. 1.1-7 Double Bus Double Breaker

BREAKER-AND-A-HALF

A more economical version is the so called Breaker-and-a-Half, as shown in Fig. 1.1-8. For simplicity, only two incoming circuits are shown. The two circuits share the same middle breaker, hence the term Breaker-and-a-Half. Normally the shared breaker is closed and both lines 3 and 4 are fed by the two Buses operating in parallel. CTs are installed on all breakers so that both differential and line protection can be provided. Line relays are served by the outboard CTs of the line breakers. Bus differential relays are served by the outboard CTs of the Bus breakers. For example, if breaker 4 needs to be removed from service, simply open breaker 4 and lines 3 and 4 are now both fed by Bus-A.

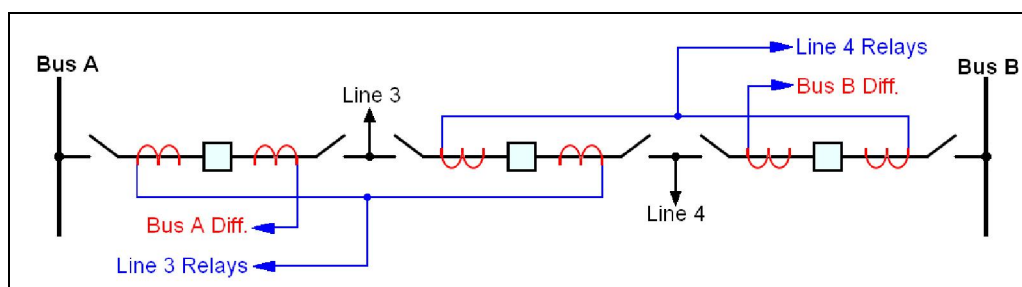


Fig. 1.1-8 Breaker-and-a-Half

Separate differential Bus protection is provided for Bus-A and Bus-B. If a fault occurs on Bus-A, all of the A side breakers will open and since the shared breakers are normally closed, all the lines are connected to Bus-B. The mid-Bus sections are protected by the line protection.

RING BUS

Another Bus arrangement commonly used is the Ring Bus, as shown in Fig. 1.1-9. Circuits are connected to a common ring, which in turn is broken into sections by circuit breakers. A fault on any line will cause the tripping of the two breakers on either side. With this arrangement, special Bus protection is not required as each Bus section is included in its associated line protection. If a circuit breaker is removed for maintenance, the Bus remains connected to the four circuits but it is now an open Bus. However, in this situation, if a fault occurs on one line, then the Bus will be split as additional breakers open.

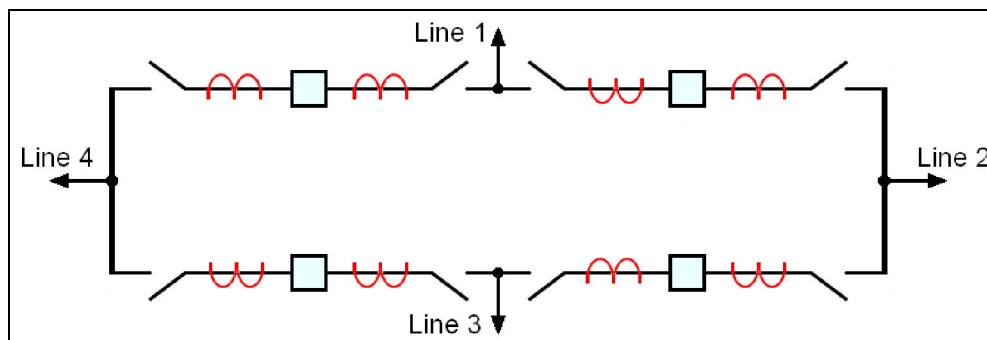


Fig. 1.1-9 Ring Bus

BUS WITH DIRECTLY CONNECTED TRANSFORMER

Fig. 1.1-10 shows a circuit connected to a Bus directly through a transformer with no breaker between the transformer and the Bus. In this case, the Bus zone protection is extended to include the breaker and outboard CT on the primary side of the transformer. A fault on the Bus or in the transformer will operate the Bus protection to trip all the connected breakers including the transformer primary.

Alternately, separate protection could be installed on the Bus and the transformer. Transformer faults would trip all the breakers as before. Then a motor operated disconnect switch installed between the transformer and the Bus would be opened and the Bus put back into service.

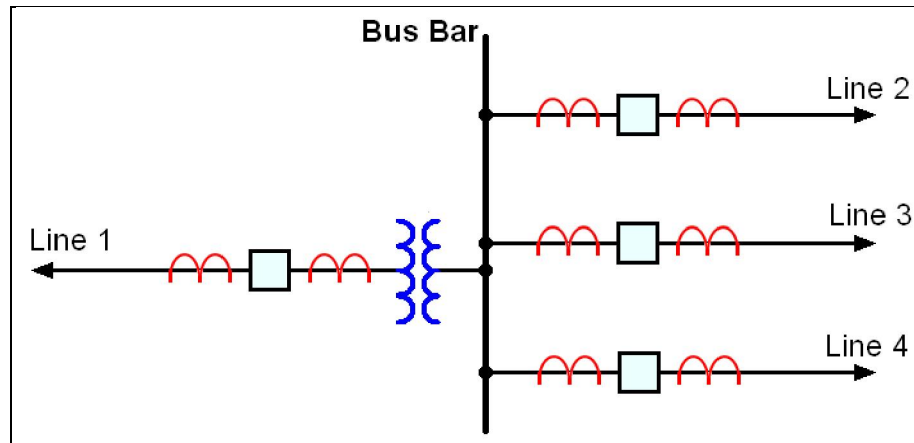


Fig. 1.1-10 Bus with directly connected Transformer

BUSBAR FAULTS

The Bus bar faults can be classified into two categories:

- One phase to earth
- Phase-to-phase (clear of earth)

A large number of Bus bar faults result from human error rather than the failure of switchgear components. With fully phase-segregated metal-clad gear, only earth faults are possible and a protective scheme needs earth fault sensitivity only. In other cases, ability to respond to phase faults clear of earth is an advantage, although the phase fault sensitivity need not be very high.

COMMON TYPES OF BUS BAR FAULTS

The three common types of Bus bar faults are:

- **Animals or birds** bridging across an insulator to ground.
- **Lightning flashover**, perhaps leading to insulator breakdown.
- **Flying objects** bridging across the Busbars.

Faults rarely occur on Buses, but if a fault does occur, it must be cleared as quickly as possible, because of the potential for extensive damage to equipment. As shown in Fig. 1.1-2, the direction of current flow forms the basis of Bus protection. To measure the total flow of current into and out of the Bus, CTs are located on the outboard side of the circuit breakers. If there is no fault on the Bus, the sum of the currents leaving is equal to the sum of the currents entering. That is, the total current is zero. Even if there is a fault on one of the transmission lines downstream, the sum of the currents is still zero as the total current entering the Bus is matching with that leaving. The downstream fault would be cleared by other protection relays activated by CTs on the inboard side of the circuit breaker. If a fault occurs on the Bus itself, the sum of the currents in and out of the Bus will no longer be zero. This will cause the protection relays to operate and trip all the breakers connected to the Bus.

BUSBAR PROTECTION

Fig. 1.1-11 shows a simple protection arrangement that is typically used in a distribution substation. As the outgoing feeders are radial, the current will not reverse if a Bus fault occurs. On this particular system the Bus tie is normally closed. Partial differential protection for Bus 1 is provided by the Time Over-Current Relay 51. If a Bus fault occurs on Bus 2, a heavy fault current flows from source 1 into Bus 1 and through the tie breaker into Bus 2. The CT currents are subtractive and therefore will not operate the Over-Current Relay.

If a fault occurs on Bus 1, heavy fault current flows into Bus 1, from source 1 and also through the Tie Breaker from source 2. The current in the two CTs will now be additive and consequently will cause the Over-Current Relay to operate. This protection also operates for a heavy fault on a Bus 1 feeder, which fails to be cleared by its own breaker. The system, therefore, operates as back-up and the setting of the relay must allow for this. A similar pair of CTs will be connected to provide partial differential protection for Bus 2.

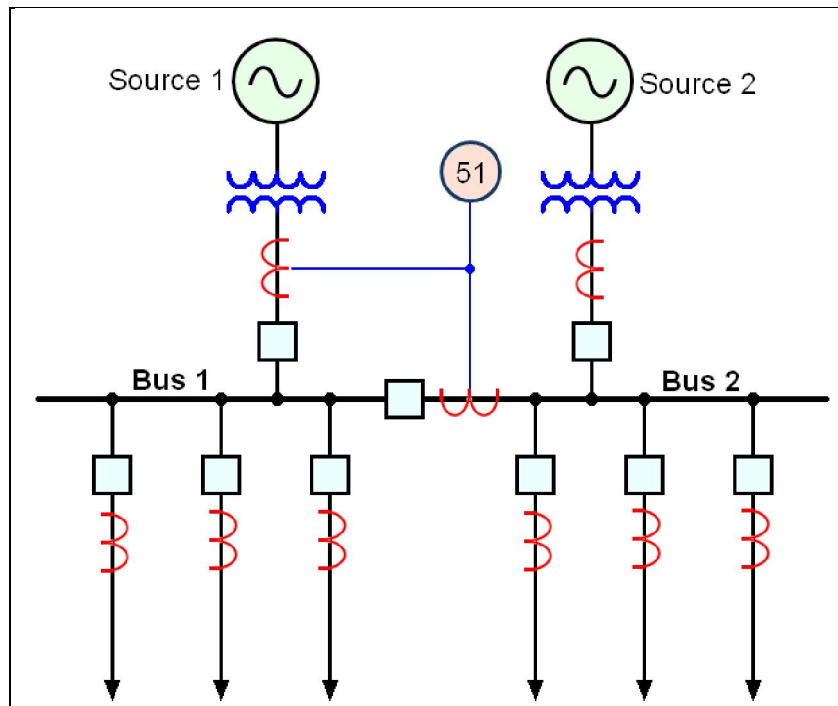


Fig. 1.1-11 Protection for Typical Distribution Substation
(Only Source 1 Protection Shown)

Fig. 1.1-12 shows the ground fault Bus arrangement as used with distribution Buses located inside metalclad switch gear. This protection scheme is based on the fact that 99% of the faults on the enclosed Bus will be to ground, generally, metallic structure. Where Ground Fault Bus protection is used, all of the metallic structure and its supports are insulated from ground. One ground connection only is provided and this passes through CT to operate an Over-Current Relay.

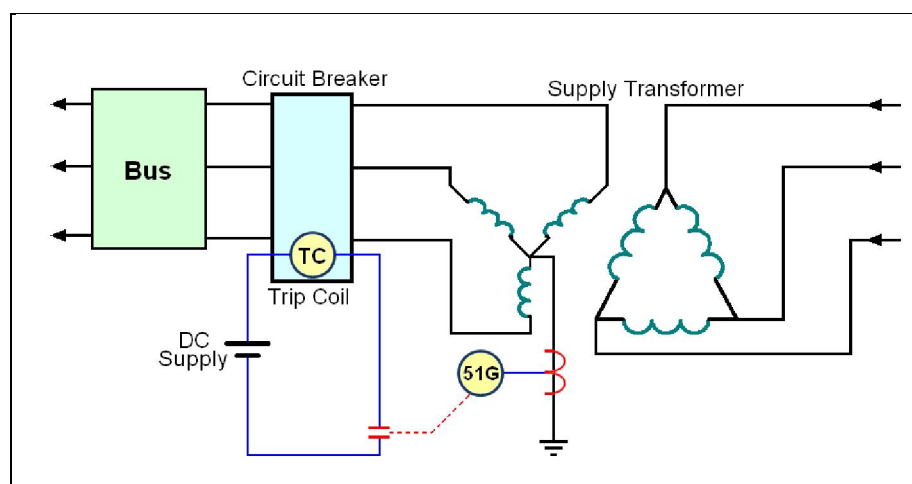


Fig. 1.1-12 Ground Fault Bus Protection

A supervisory contact is wired into the Over-Current Relay tripping circuit in order to prevent tripping by stray ground currents. The supervisory contact is controlled by a CT in the system neutral ground. If the ground current through the CT is not due to a system fault, then there will be no flow of current in the system neutral and the supervisory contact will be held open. A big disadvantage of this scheme is the possible danger to personnel near the switchgear housing, as with heavy fault current the Bus housing may develop a potential above ground. For this reason, it is rarely used today.

The simplest method of providing differential protection is to fit CTs to measure the current in all circuits connected to the Bus. For clarity, Fig. 1.1-13 shows one phase only of each line. The secondary side of the CTs is all connected in parallel and the residual current (current difference) passes through an Over-Current Relay (51). If the current in and out is balanced, the residual sum of the secondary currents in the CTs is zero. If there is a fault on the Bus, some or all of the circuits will feed into the Bus. The current in the CT secondary will now be additive and the resulting residual current will operate the Time Over-Current Relay. For this protection to operate successfully, it is essential that the CTs accurately represent the primary currents in the secondary.

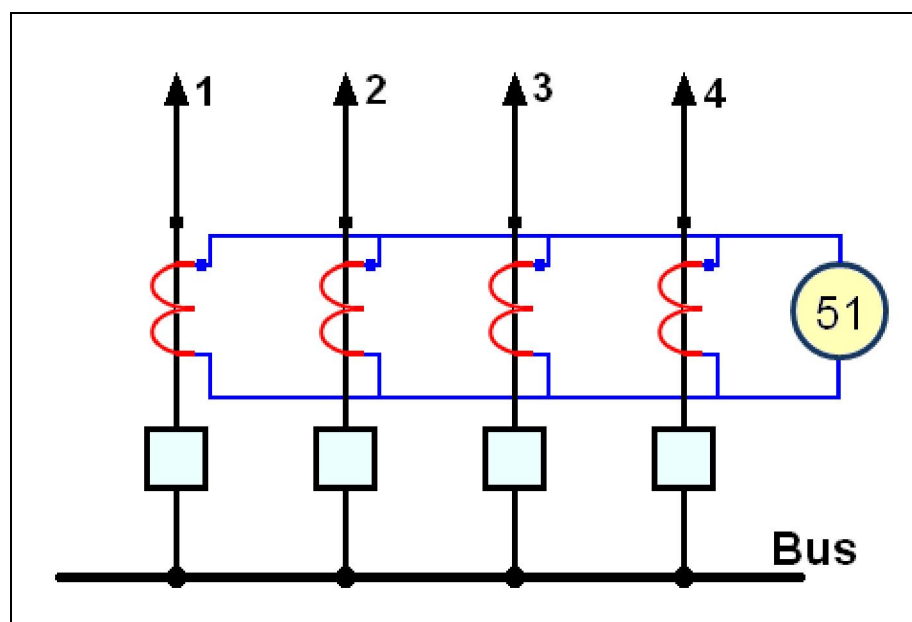


Fig. 1.1-13 Bus Differential Protection

In practice, this accuracy is difficult to achieve, especially where the measured currents are of greatly different values. This is not a problem with faults on the Bus, because the current in all of the connected circuits, now feeding into the Bus, would be of a similar magnitude. However, with a through fault, the magnitude of primary current will be greatly increased in the faulty circuit.

Fig. 1.1-14 shows a heavy fault on line 4. Bus protection must not operate under these circumstances, as it is an external fault. The actual current in line 4 is the sum of the currents in lines 1, 2 and 3. Therefore, it is likely that the current in the CT secondary will not accurately represent the primary current. This is especially true if the CT on line 4 becomes saturated due to the heavy current flow.

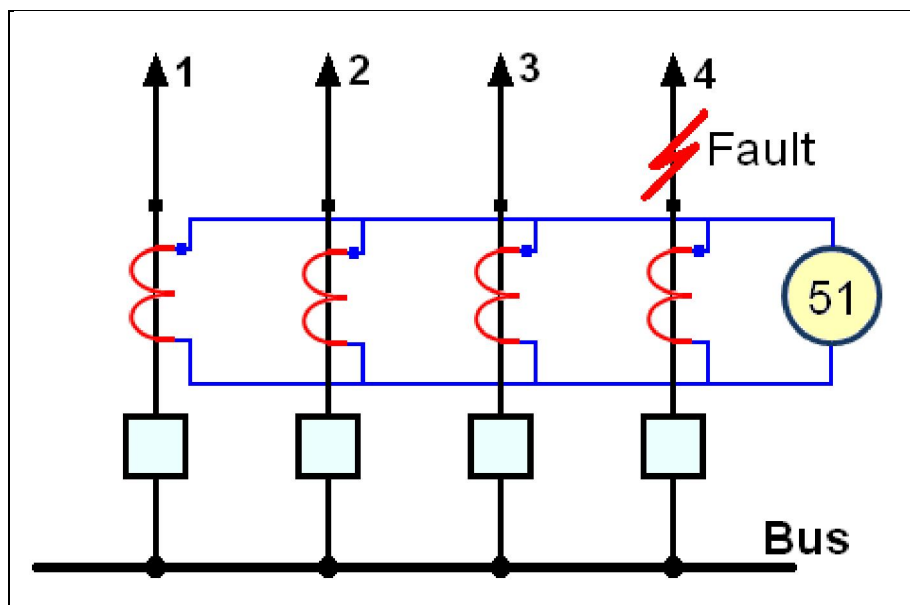


Fig. 1.1-14 Bus Differential Protection with Through-Fault

The secondary current on this saturated CT will be much lower than the sum of the secondary CTs 1, 2 and 3. The resulting unbalance would look like a Bus fault and cause the relay to operate. The unbalance in secondary current is greatly exaggerated during the first 10 to 20 cycles of the fault. This is due to the transient that occurs in the primary current at the initiation of the fault. Fig. 1.1-15 shows the first 30 cycles of the fault.

The two effects resulting from CT's saturation, are:

- a) The secondary current not increasing in proportion to the primary, exceeds the saturation point (saturation usually occurs at about 20 times CT's rated current).
- b) The secondary current is actually reduced and distorted due to the declining DC component of the transient fault current, as shown in Fig. 1-15.

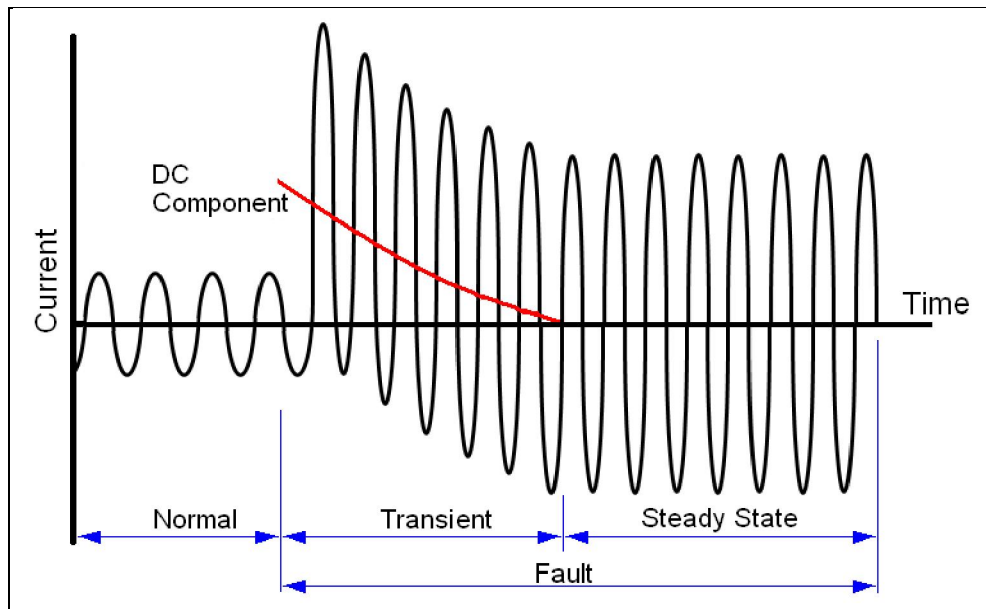


Fig. 1.1-15 Fault Current

This means that for the first few cycles after initiation of the fault, the output of the heavily loaded CT will be most unreliable and will probably cause false tripping. The simplest way to get around this problem is to use the delay of the Time Over-Current Relay to ride through the transient period. A time delay of about .2 seconds (12 cycles) is sufficient in most applications.

More sophisticated arrangements are needed for protection of high voltage Buses. One improved method uses Directional Relays fitted to every circuit connected to the Bus, as shown in Fig. 1.1-16. The operating contacts from the relays are all connected in series. When current flowing is out of the Bus, its respective relay contact is held open. Conversely, when current flowing is into the Bus, the contact is closed. For a Bus fault, current will flow into the Bus from all circuits and, consequently, all of the

contacts will be closed, to trip all breakers. Where radial feeders are connected, there would be no reverse current into the Bus and therefore, these are not included in the scheme. Because there are many contacts wired in series, this protection scheme could fail to operate due to one faulty pair of contacts. Another problem is that the directional relay requires a polarizing source. If this is taken from a voltage transformer on the Bus, the voltage may well fall close to zero during a Bus fault, and therefore, the directional relays would not operate.

A further potential problem may result from weak sources(s) during certain switching sequences as the contact associated with weak source may not close.

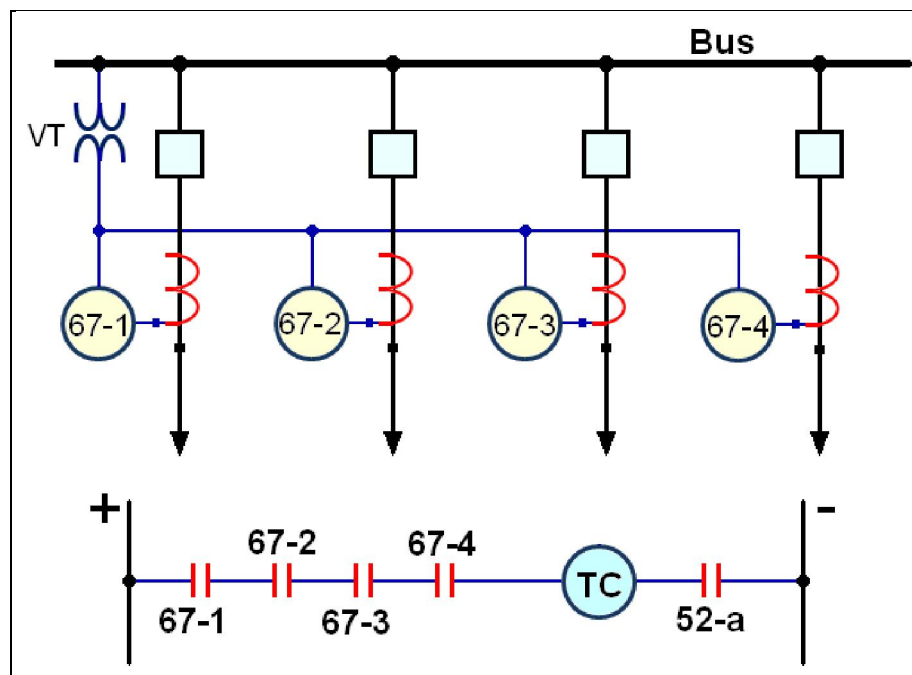


Fig. 1.1-16 Directional Comparison Scheme

SUMMARY

- The CTs are usually located in the circuit breaker Bushings.
- A Tie Breaker splits a Bus into two halves to open and isolate the faulty half of the Bus leaving the remaining section of Bus in service.

- In a double Bus arrangement, each circuit can be connected to either Bus-A or Bus-B according to the selection of the circuit disconnects and each Bus is provided with differential protection, separately.
- A large number of Bus bar faults result from human error rather than the failure of switchgear components.
- The three common causes of bus bar faults are- animals or birds bridging across an insulator to ground, lightning flashover, perhaps leading to insulator breakdown and Flying objects bridging across the Bus bars.
- The direction of current flow forms the basis of Bus protection.
- To measure the total flow of current into and out of the bus, CTs are located on the outboard side of the circuit breakers.

GLOSSARY

Intrinsically:	Essentially, fundamentally
Dislocation:	Displacement
Outboard:	On the other side, outside
Sophisticated:	Complicated

REVIEW EXERCISE

BUSBARS, FAULTS AND PROTECTION

- In Fig. 1.1-17, lines 1 and 2 are carrying 500 Amps and 700 Amps, respectively. The total current supplied by generators 1 and 2 is _____ Amps.

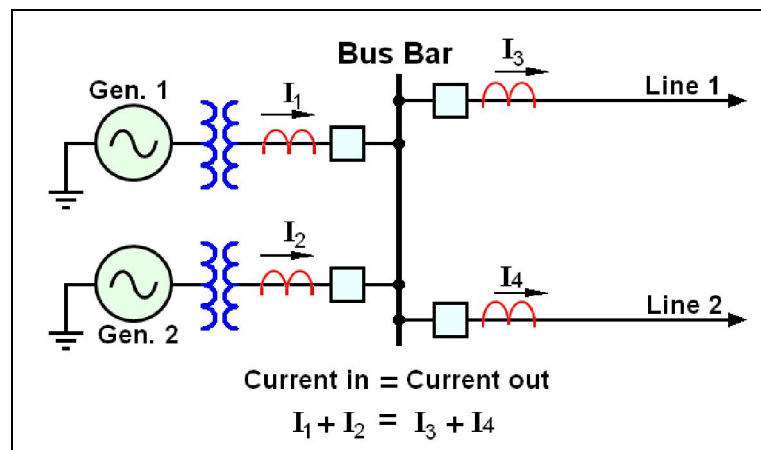


Fig. 1.1-17 Single Bus Protection

- 200
 - 1200
 - 1000
 - 600
- In Fig. 1.1-17, a fault occurs on line 2 causing its current to increase to 2500A, while Line 1 is still carrying 500 Amps. The total current supplied by generators 1 and 2 during the fault is _____ Amps.
 - 500
 - 1,200
 - 3,000
 - 2,000
 - In Fig. 1.1-17, a 10,000 Amps ground fault occurs on the bus. Lines 1 and 2 currents are unchanged carrying 500 Amps and 700 Amps, respectively. The total current supplied by generators 1 and 2 during the fault is _____ Amps.
 - 10,000
 - 11,500
 - 12,000
 - 11,200

4. In Qs 1, 2 and 3, the bus is provided with differential protection. The bus protection sees unbalanced current that is the difference between the current in and out of the bus. The unbalanced currents in Qs 1, 2, and 3 are _____, _____ and _____ Amps, respectively.

a) Q.1-0 Q.2-0 Q.3-10,000	b) Q.1-0 Q.2-10,000 Q.3-0
c) Q.1-10,000 Q.2-0 Q.3-0	d) Q.1-0 Q.2-1200 Q.3-10,000

5. In Fig. 1.1-17, air disconnect switches would normally be associated with the Bus, _____ and _____ the circuit breakers.
6. In Fig. 1.1-18, the purpose of the bus tie breaker is _____.

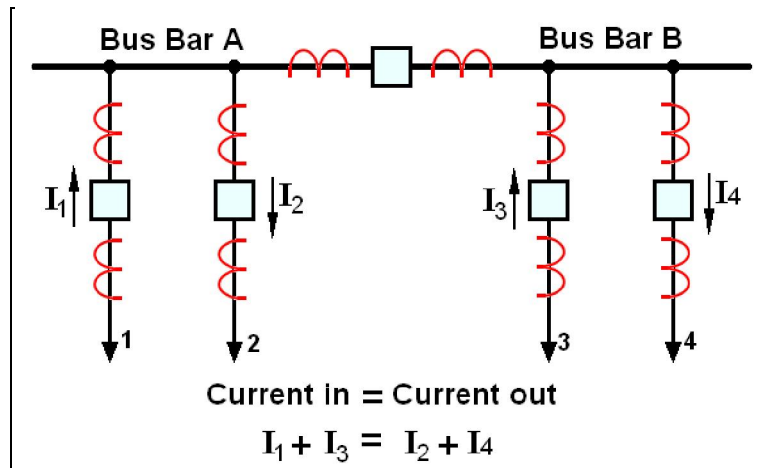


Fig. 1.1-18 Split Bus with Tie Breaker

7. In Fig. 1.1-19, the purpose of the transfer bus is _____.

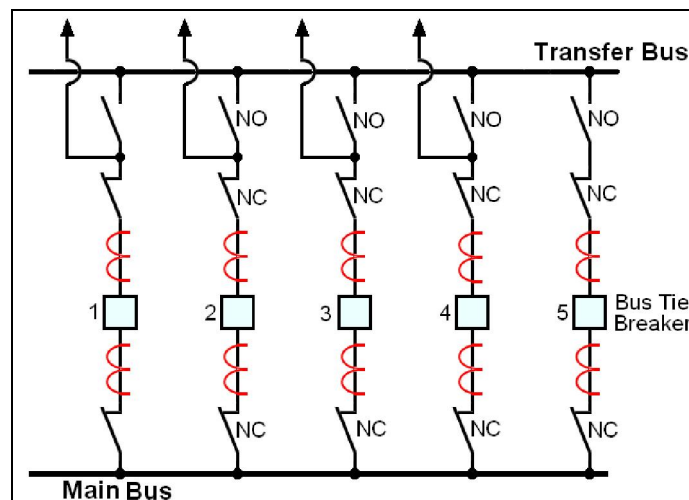


Fig. 1.1-19 Transfer Bus

8. In Fig. 1.1-20 for Double Transfer Bus, _____.

- Each circuit can be connected to either Bus-A or Bus-B according to the selection of the circuit disconnects.
- Bypass Disconnect Switches are provided around each circuit breaker.
- Breaker 1 at line 1 is in service and all other breakers are out of service with Bus-A functioning as the transfer Bus and bypass breaker closed at line 1.
- Both (a) and (b)

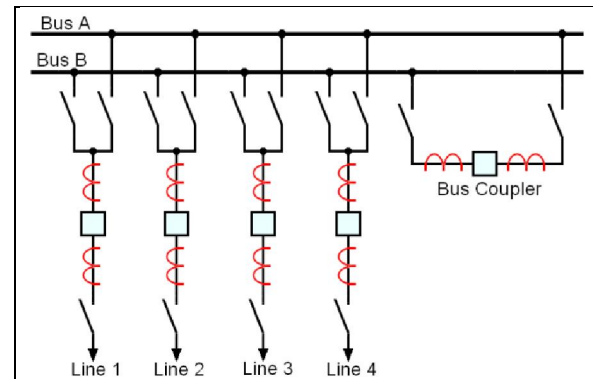


Fig. 1.1-20 Double Transfer Bus

9. In Fig. 1.1-21 for Double Bus Double Breaker, a Bus fault will trip all of the breakers connected to that Bus, because _____.

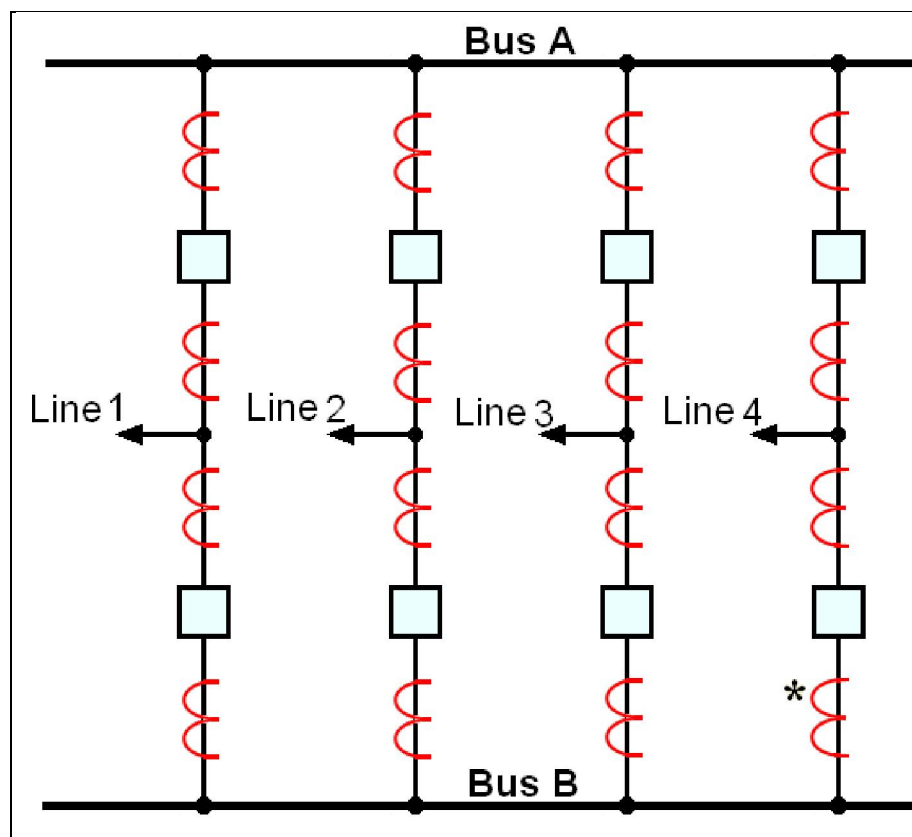


Fig. 1.1-21 Double Bus Double Breakers

10. The Breaker-and-a-Half arrangement shown in Fig. 1.1-22 means _____:

- | | |
|---|--|
| a) A common middle breaker shared by two circuits | b) Half a breaker shared by two circuits |
| c) One and a half breaker shared by two circuits | d) One and a half breaker not shared by two circuits |

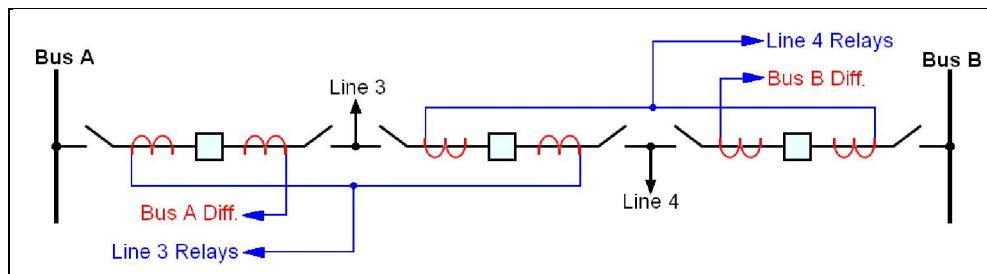


Fig. 1.1-22 Breaker-and-a-Half

11. In Fig. 1.1-23 for Ring Bus, all circuit breakers are closed when the Bus is operating normal.

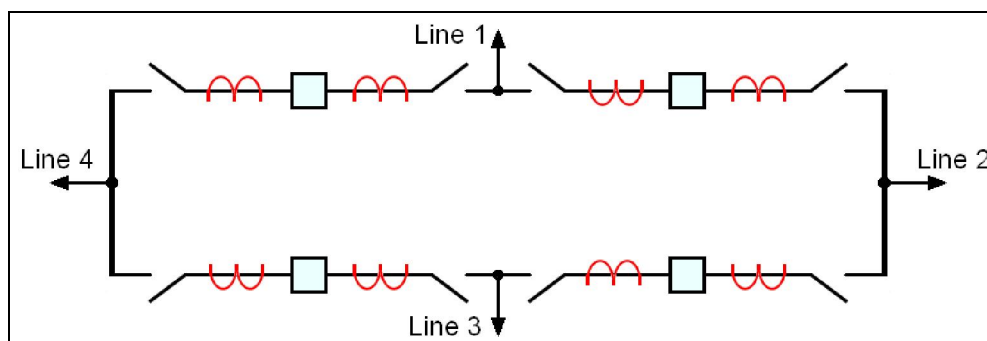


Fig. 1.1-23 Ring Bus

- | | |
|---------|----------|
| a) True | b) False |
|---------|----------|

12. In Fig. 1.1-23 for Ring Bus, a fault on any line will cause the tripping of the _____ breakers on either side.

- | | |
|------|-----------|
| a) 1 | b) 2 |
| c) 4 | d) a or c |

13. In Fig. 1.1-24 for a Bus with directly connected Transformer, _____

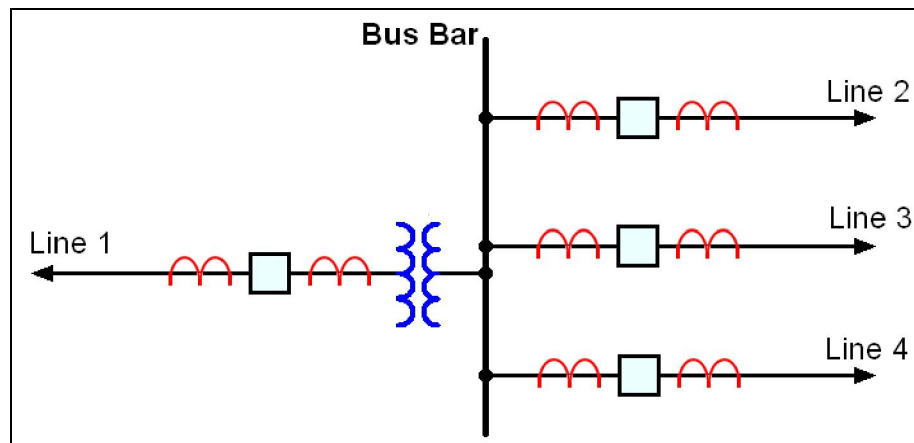


Fig. 1.1-24 Bus with directly connected Transformer

- The Bus zone protection is extended to include the breaker and outboard CT on the primary side of the transformer.
- A fault on the Bus or in the transformer will operate the Bus protection to trip all the connected breakers including the transformer primary.
- separate protection could be installed on the Bus and the transformer. Transformer faults would trip all the breakers.
- All of above

14. The Bus bar faults can be classified into two categories:

- _____
- _____

15. The three common types of Bus bar faults are:

- _____
- _____
- _____

16. In Fig. 1.1-25, Relay 51 will trip for a fault on Bus 1, but not on Bus 2 because _____:

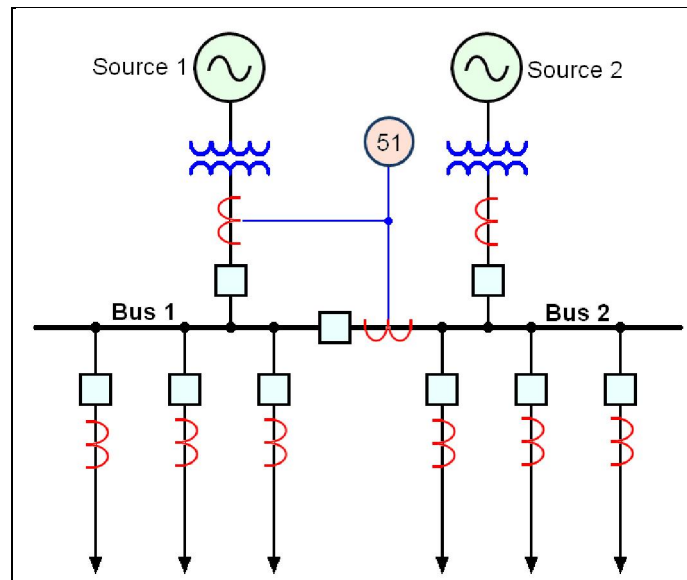


Fig. 1.1-25 Protection for Typical Distribution Substation
(Only Source 1 Protection Shown)

17. In Fig. 1.1-27 for Bus Differential Protection:

- i) The secondary side of the CTs are all connected in _____ and the _____ current passes through the Time Over-Current Relay (51).
- ii) If the current in and out is balanced, the residual sum of the secondary currents in the CTs is zero
 - a) True
 - b) False
- iii) If there is a fault on the Bus, some or all of the circuits will feed into the Bus and the current in the CT secondaries will be _____ and the resulting residual current will operate the Time Over-Current Relay.

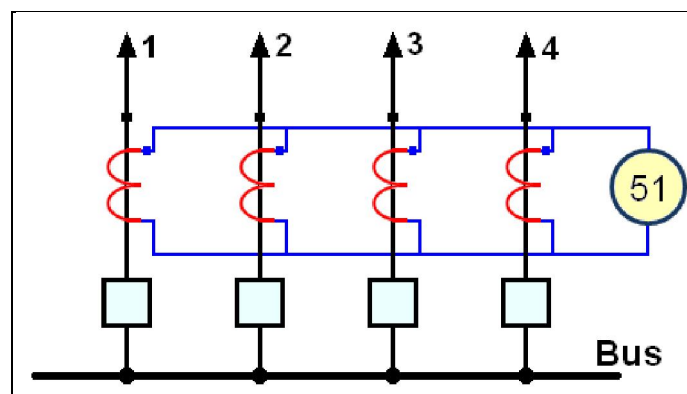


Fig. 1.1-27 Bus Differential Protection

18. In Fig. 1.1-28 for Directional Comparison Scheme in Bus Differential Protection,:

- i) The operating contacts from the relays are all connected in series, so that when current flowing is _____ of the Bus, its respective relay contact is held _____. Conversely, when current flowing is _____ the Bus, the contact is _____.
- ii) For a Bus fault, current will flow into the Bus from all circuits and, consequently, all of the contacts will be closed, de-energizing the relay and will not trip all breakers.
 - a) True
 - b) False
- iii) This protection scheme may fail to operate due to one faulty pair of contacts out of many contacts wired in _____.
- iv) If polarizing source is derived from a voltage _____ or the _____, the voltage may well fall close to _____ during a Bus fault, and therefore, the directional relays would not operate to trip the circuit breakers.

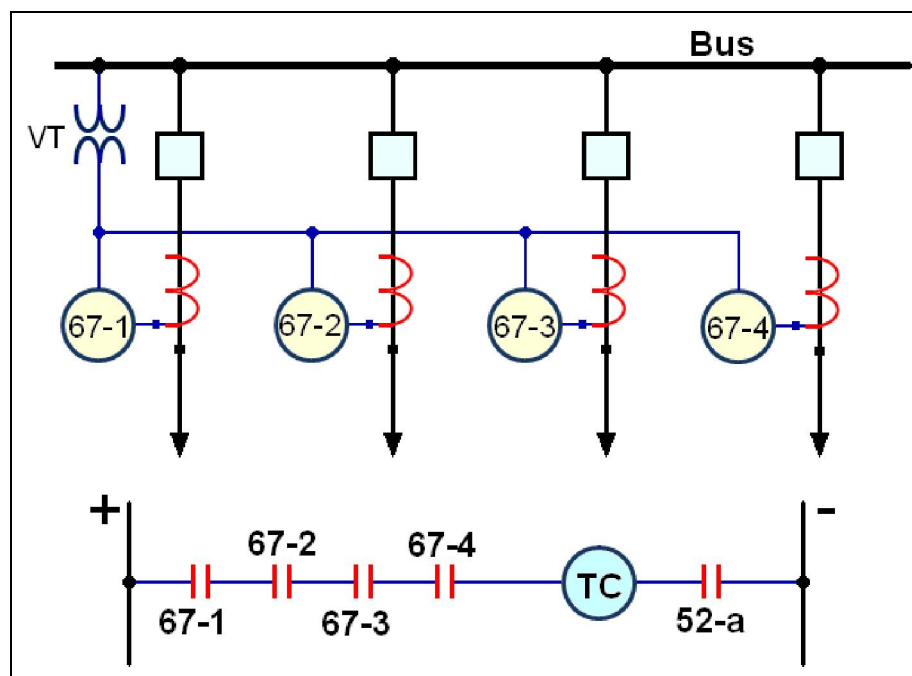
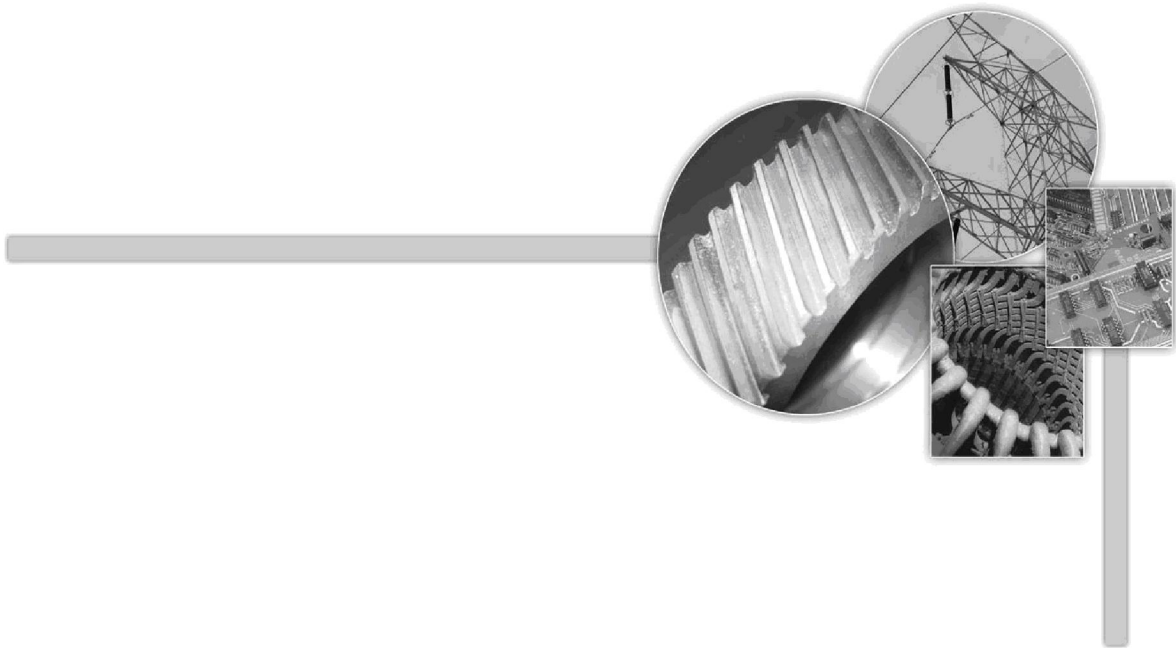


Fig. 1.1-29 Directional Comparison Scheme



LESSON 1.2

BUS BAR PROTECTION BY DIFFERENTIAL RELAYS

LESSON 1.2

BUS BAR PROTECTION BY DIFFERENTIAL RELAYS

OVERVIEW

This lesson discusses the requirements of the Bus bar Protection and concentrates to the bus bar protection using differential relay schemes. It scopes out linear coupler system, high-speed differential protection.

OBJECTIVES

Upon completion of this lesson, the trainee will be able to:

- List Busbar Protection requirements.
- Identify the differential bus protection.
- Verify the linear coupler system.
- Illustrate high speed differential protection.
- Explain Bus Total Differential Relaying.
- Demonstrate Selective Partial Differential Schemes.

INTRODUCTION

Bus Protection by Differential Relay Systems is more straightforward than transformer protection systems because the number of variables is reduced. There is no ratio or phase angle change or appreciable inrush. Practically, the Bus protection is the most difficult to implement because of the severity of an incorrect operation on the integrity of the system. A Bus is one of the most critical system elements. The connecting points of elements, number of transmission lines, and any incorrect operation would cause the loss of all the elements. This would have the same disastrous effect as a large number of simultaneous faults. However, without Bus protection (not practiced these days), if a Bus fault occurs, the remote ends of lines must be tripped. In effect, that would create a worse situation than the loss of all elements at the Bus for two reasons:

- a) The loss of remote ends will also result in the loss of intermediate loads, if any existing.
- b) For a larger system, it is increasingly difficult for the remote ends to see all faults pertaining to infeeds.

BUS PROTECTION REQUIREMENTS

Basically, Busbar Protection is not different from protection of other circuits. The two essential requirements for Busbar Protection are speed and stability to account for the overall power system safety and reliability, which are discussed, as follows:

SPEED

Bus bar protection is primarily concerned with the following:

- i) Limitation of consequential damage.
- ii) Removal of Bus faults in less time than could be achieved by back-up line protection with the object of maintaining system stability.

The basis of most present schemes is a differential system using either low impedance biased or high impedance unbiased relays capable of operating within one cycle timing at a very moderate multiple of fault setting. The operating time of the tripping relays must be added to this for an overall tripping time of less than two cycles that can be achieved. With high speed circuit breakers, complete fault clearance may be obtained in approximately 0.1 second corresponding to 6 cycles at 60 Hz.

STABILITY

The stability of Bus protection is of paramount importance. It is clear that unless protection stability is absolute, the degree of disturbance to which the power system is likely to be subjected may be increased by the installation of Bus protection. However, for the complete stability of a correctly applied protective system, dangers may exist in practice for the following three reasons:

- a) Interruption of the secondary circuit of a Current Transformer will produce an unbalance, which might cause tripping on load, depending on the relative values of circuit load and effective setting. It would certainly do so during a through-fault, producing substantial fault current in the circuit.
- b) A mechanical shock of sufficient severity may cause tripping operation.
- c) Accidental interference with the relay, arising from a mistake during maintenance testing, may lead to tripping operation.

BUS PROTECTION BY DIFFERENTIAL RELAYS

In order to maintain high order of integrity needed for Bus protection, it is an almost invariable practice to make tripping depend on two independent measurements of fault quantities. Substation Bus Protection is most universally accomplished by differential relaying. This method makes use of “Kirchhoffs Law of Currents”, which states that the sum of all currents entering or leaving a point (the substation bus) must, vectorially, equal to zero.

In practice, this type of protection is accomplished by balancing the CT secondary currents of all of the circuits connected to the Bus and then bridging this balanced circuit with a relay operating coil. If two systems of differential or other similar type are used, they should be energized by separate Current Transformers in the case of high impedance unbiased differential schemes. The duplicate donut CT cores may be mounted on a common primary conductor but independence must be maintained through the secondary circuit.

In the case of low impedance, biased differential schemes used with unequal ratio CTs, the scheme can be energized from either one or two separate sets of main Current Transformers. The double feature operation before tripping can be maintained by the provision of two sets of ratio matching interposing CTs per circuit. The basic requirement is that the total Bus Protection scheme must provide the degree of selectivity necessary to differentiate between an internal and an external fault.

UNEQUAL CORE SATURATION IN CTs

Bus Differential Protection is the most sensitive and reliable method of protection for station buses. The particular problem in this application is the large number of circuits involved and, hence, different energization levels in the various circuits during external faults causing unequal core saturation of the Current Transformers used in the system. This unequal core saturation is due to the large variation of current magnitude and residual flux in the individual CTs used in the system, particularly during a fault. In particular for a close-in external fault, one CT will receive the total contribution from the Bus while the other CTs will only see the contribution of individual lines. A heavy external fault tends to saturate the CT in the faulted circuit and cause an inaccurate unbalance, which can wrongly operate the relay. This problem has been overcome by linear couplers or by employing stabilizing resistors in the operating circuit of the relay.

For example, with an external fault on one circuit of a six-circuit bus, five of the Current Transformers may supply varying amounts of fault current but the sixth and faulted circuit must balance out the total of all the others.

Thus, it is energized at a much higher level near saturation or frequently with varying degrees of saturation leading to higher false differential currents. For the same general reasons, the DC saturation also is unequal. The DC saturation is much more severe than AC saturation where a small amount of DC from an asymmetrical fault wave may saturate the transformer core and appreciably reduce the secondary output below the actually rated. The three most common methods of solving the Bus Differential Protection problems are:

- i) Eliminating iron in the Current Transformer as in Linear Coupler System.
- ii) Using multi-restraint variable percentage Differential Relay specifically designed to be insensitive to DC saturation.
- iii) High impedance voltage operated Differential Relay with a series resonant circuit to limit sensitivity to the DC component.

LINEAR COUPLER SYSTEM

Linear couplers are CTs without an iron core. The magnetizing reactance of these transformers is linear, and is very small compared to that of a steel-cored CT. The secondary windings are very limited for current they can deliver. The linear coupler operates as a current-to-voltage converter; the voltage in the secondary circuit is a reproduction of the primary current.



Fig. 1.2-1 Linear Coupler Air Cored Transformer

The transformation ratio is practically constant. The main use of linear couplers is in applications where saturation of the CT presents a major problem as in the case of bus protection applications. Linear couplers are not much in use, since they must be installed in addition to CTs, which are needed for most relaying and metering functions.

The selected current transformers should be satisfied for the ideal linear couplers for the required energy output to operate the low-energy high speed relays. It should be provided with impedance taps to be selected so that the impedance of the relay can be more closely matched to the impedance of the linear couplers for maximum signal transfer ratio required.

When the relay and coupler impedance's are matched, there is a maximum amount of operating energy transferred from the coupler to the relay. Since the standard linear coupler induces 5 volts secondary per 1000 amperes primary, the couplers (unlike Current Transformers) can be safely open-circuited making them less hazardous to electric shock and therefore, danger to personnel from high voltages is eliminated.

SATURATION FROM DC COMPONENT OF FAULT CURRENT

Fig. 1.2-2 compares the DC saturation curves of CT and linear coupler exhibited by an asymmetrical fault current, where a DC component is present. The DC saturation curve rises much slower linearly in the coupler because of long DC time constant (large L/R ratio) as compared to steeper slope of CT curve due to short DC time constant (small L/R), resulting in transient saturation of the CT. For most substation buses using linear couplers having long time constants and operating in linear portion of the curve, no appreciable DC saturation results as compared to that of CTs.

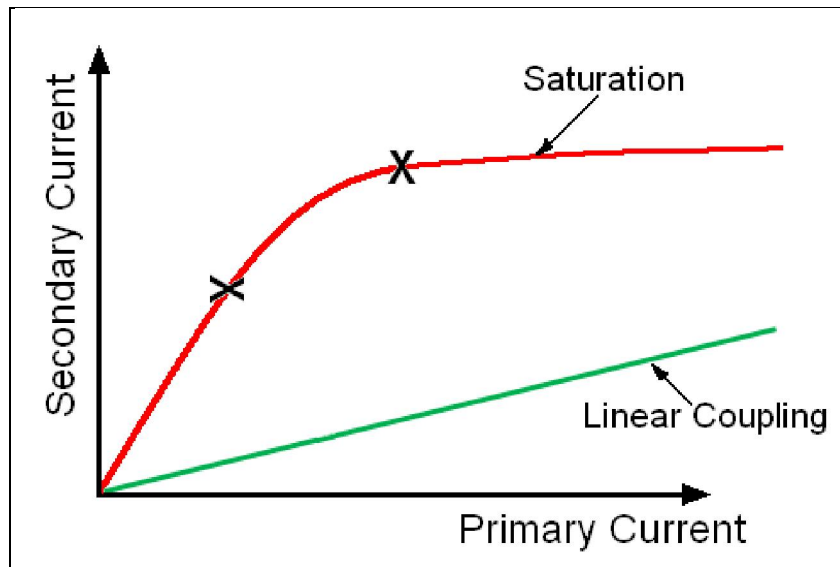


Fig. 1.2-2 Current Transformers and Linear Coupler Saturation Curves

The presence of a prolonged DC component will produce a severe transient saturation. Even though it would be technically possible to design a Current Transformer that would not saturate, calculations show that such Current Transformers would require a cross section of iron as much as one hundred times larger than Current Transformers of standard construction.

BUS PROTECTION USING LINEAR COUPLERS (INTERNAL FAULT)

The linear coupler method of differential protection is a voltage differential scheme with all coupler outputs in series. This is illustrated in Fig. 2-3(a-b) for a typical four-circuit bus system with typical values for an internal and external fault.

In Fig. 1.2-3 for an internal fault on the bus drawing total current of, say 8,000 Amps, each of the transmission lines contributes to feed the fault current, as indicated. Accordingly, each coupler will contribute its output voltage to the relay depending on individual primary circuit current giving a total of 40 volts across the relay operating coil and the relay will trip.

Linear Coupler Output = 5V/1000 Amps

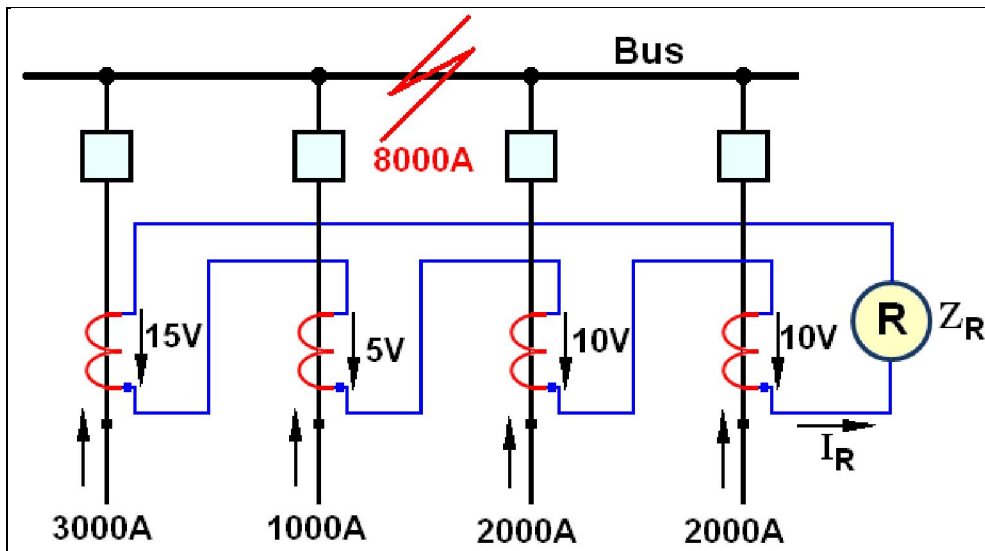


Fig. 1.2-3 Bus Protection using Linear Couplers (Internal Fault)

BUS PROTECTION USING LINEAR COUPLER (EXTERNAL FAULT)

In Fig. 1.2-4 for an external fault on line 4, we may have, say 3,000A entering in line 1, 1000A in line 2 and 2000A in line 3 and 6000A flowing to the fault on line 4. As the linear coupler does not suffer from saturation effects, the algebraic sum of the individual output voltages will be zero, resulting in no tripping of the relay for the external fault. This relay is highly sensitive and will trip in about one cycle (≈ 16.67 ms), thus providing high speed operation.

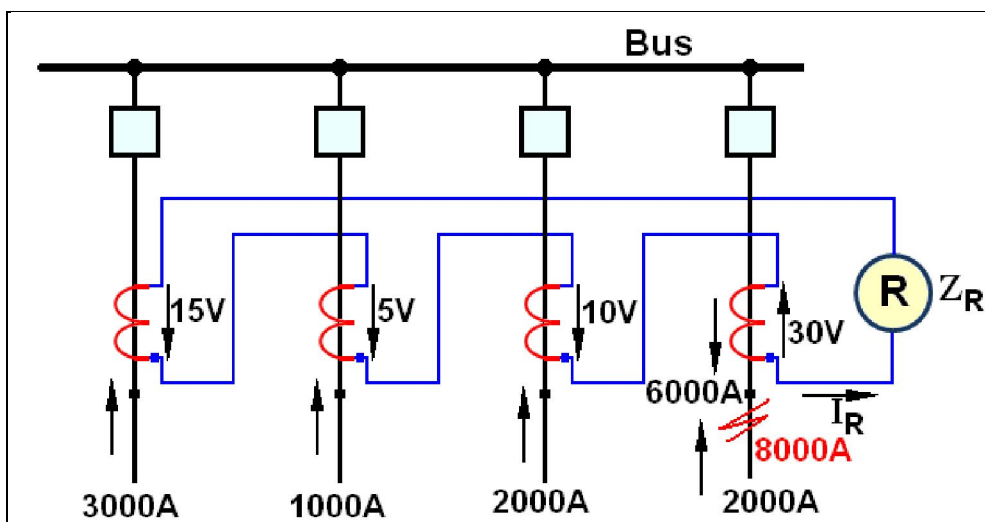


Fig. 1.2-4 Bus Protection using Linear Couplers (External Fault)

With the simple series circuit as shown in Fig. 12-3 & 4.

$$I_R = \frac{E_{SEC}}{Z_R + \sum Z_C} = \frac{I_P \times M}{Z_R + \sum Z_C}$$

Where:

- I_R = Current in linear coupler secondaries in series with relay
- E_{SEC} = Voltage induced in linear coupler secondary
- I_P = Primary current rms symmetrical
- M = Mutual reactance = 0.005 Ω for 60 cycles
- Z_C = Self impedance of linear coupler secondary
- Z_R = Impedance of relay

HIGH SPEED DIFFERENTIAL PROTECTION

BUS DIFFERENTIAL WITH CURRENT DIFFERENTIAL CIRCUIT (BALANCED LOADS)

Fig. 1.2-5 shows a numerical example of a simple current differential. For simplicity, only one phase on each line is shown. Assuming the CT ratios to be identical ($n_i = 100:1$) for a rating of 280 Amps primary, the magnitude of the secondary current in each CT secondaries is 3 Amps with the forward direction of flow for Lines 1, 2 and 3 on the left of the Bus, as shown in Fig. 1.2-5.

Similarly, the magnitude of the secondary current in each CT secondaries for Lines 4, 5 and 6 on the right of the Bus is 3 Amps with the reverse direction of flow. When the loads are balanced, the secondary currents cancel out with no current passing through the relay operating coil because the incoming and outgoing currents at the relay are equal.

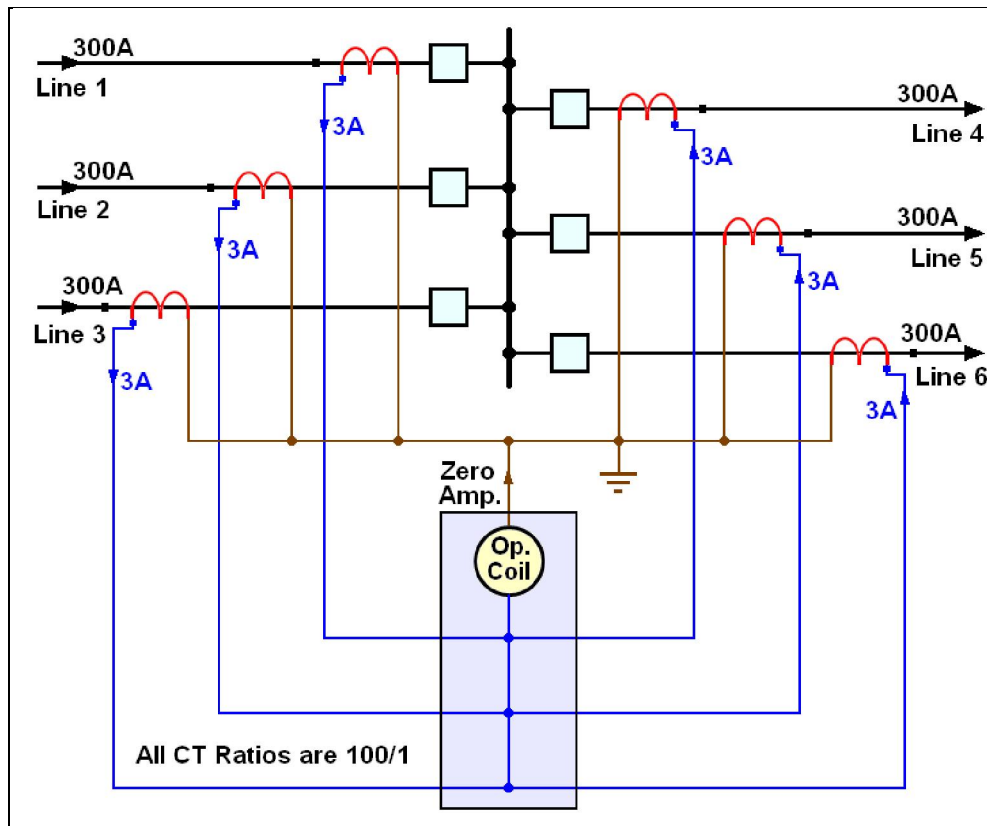


Fig. 1.2-5 Bus Differential with Current Differential Circuit (Balanced Loads)

BUS DIFFERENTIAL WITH CURRENT DIFFERENTIAL CIRCUIT (INTERNAL FAULT)

Fig. 1.2-6 shows the situation when an internal fault occurs on the Bus with a magnitude of 18,000A. All six lines feed the fault current into the Bus. Depending upon the reactance of each line from its respective source, the fault current flowing will probably be the same on each line, approximately 3,000A with 30A flowing in each CT secondary. This is six times the secondary rating of 5A; well within the range of 90 % accuracy for protection type CTs allowing approximately twenty times rated current. These secondary currents are all additive so that 180A passing through the relay operating coil would trip all the Bus breakers.

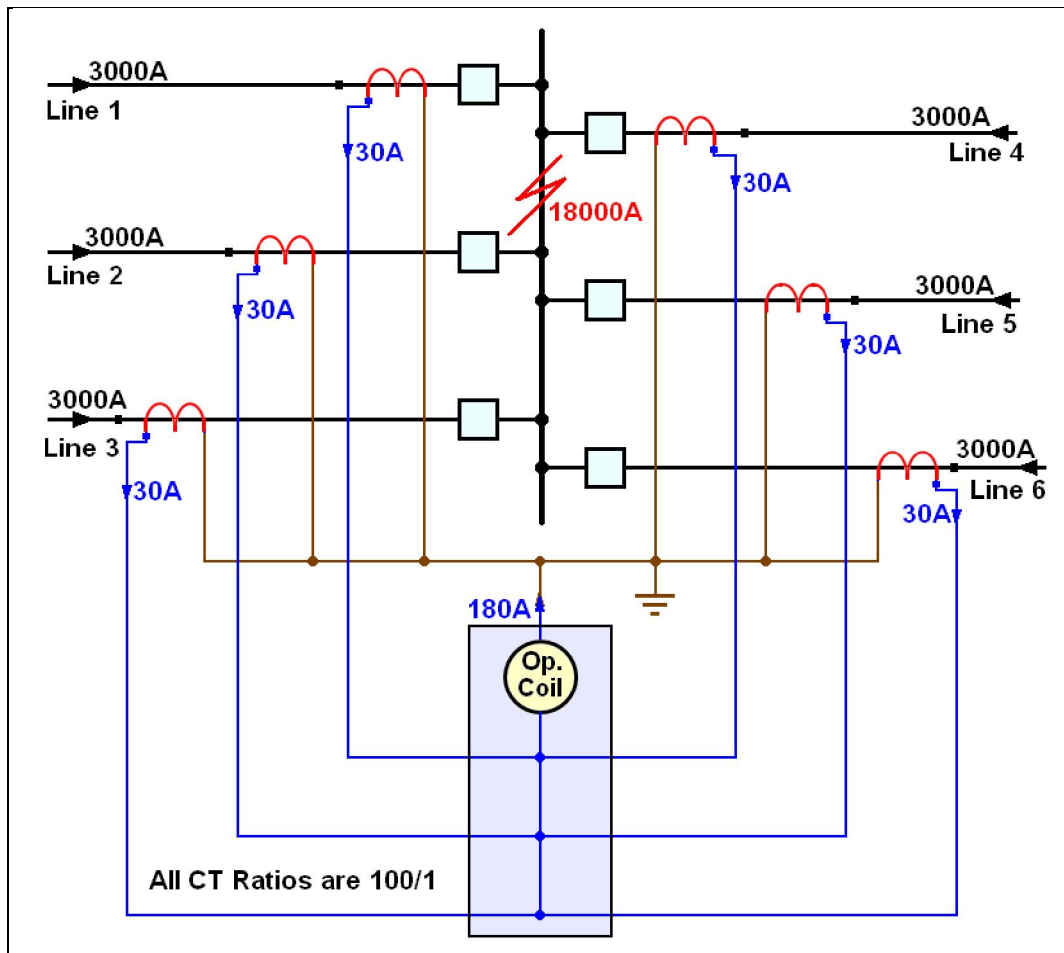


Fig. 1.2-6 Bus Differential with Current Differential Circuit (Internal fault)

BUS DIFFERENTIAL PROTECTION WITH CLOSE-IN LINE FAULT

Fig. 1.2-7 shows a fault on line 4 fairly close to the breaker with a fault magnitude of 18,000 Amps. Lines 1, 2, 3, 5 and 6 will each feed 3,000A into the Bus and 15,000A out from the Bus through line 4 to supply the fault current. Line 4 also feeds 3,000A to the fault so that:

$$\text{Total Fault Current} = 15,000\text{A} + 3,000\text{A} = 18,000\text{A}$$

The currents in each of five CT secondary should be 30A with 100:1 turn's ratio producing 150A, cancelling out 150A reverse current on the fault CT secondary circuit. As a result, the resultant zero current is passing through the relay inhibiting the operation of the relay and that is normal for an external fault provided no saturation occur on any of the CTs contributing the fault current.

But in practice, if the CT on line 4 with external fault is over its saturation limit, the relay will probably operate incorrectly as the level of current in the faulty line may be over 30 times its rating, as shown in Fig. 1.2-7.

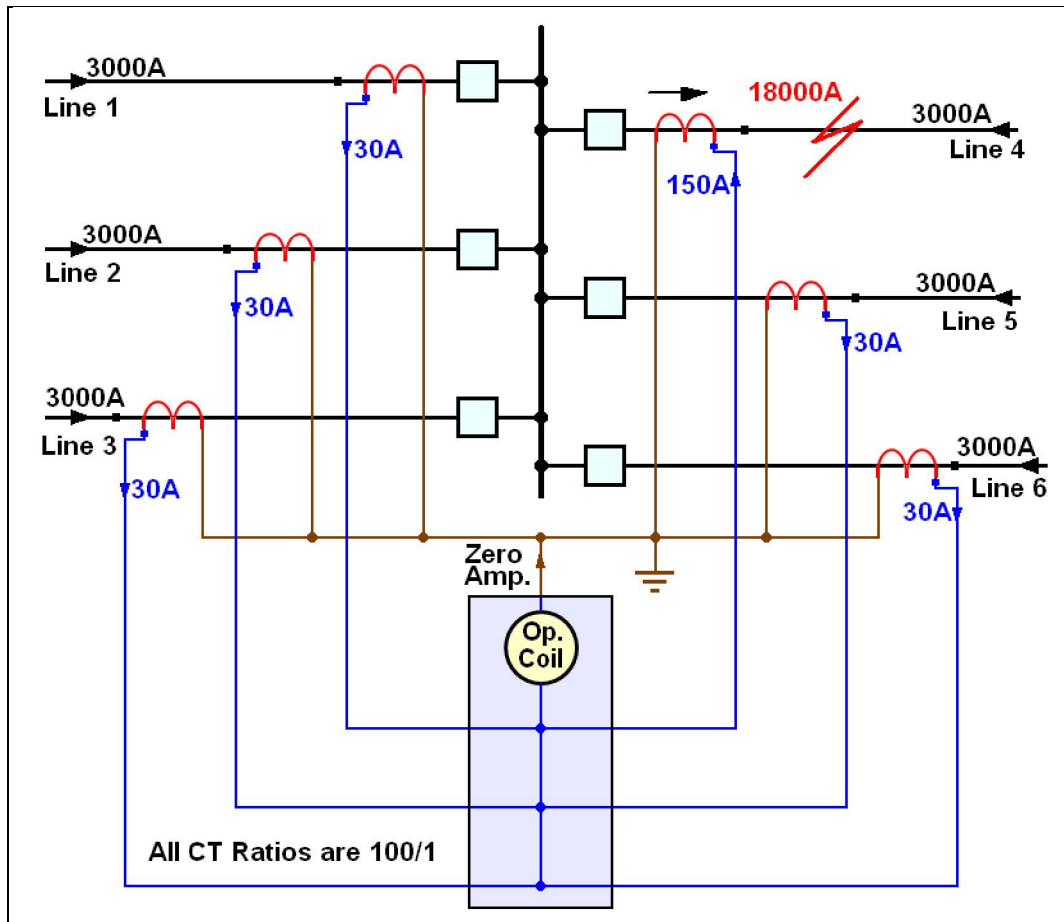


Fig. 1.2-7 Bus Differential Protection with Close-In Line Fault

EFFECT OF FAULT CT IN SATURATION FOR CLOSE-IN LINE FAULT

As shown in Fig. 1.2-8, if the CT on line 4 with external fault is over its saturation limit, it is likely that its secondary current may be, say 110A instead of 150A so that 40A difference restraint current proportional to 110A is passing through the operating coil of the relay. In this case, the percentage differential is the operating coil current (40A) divided by the total restraint current (110A), which equals approximately 36%:

$$\text{Percentage differential} = (40\text{A}/110\text{A}) \times 100 \approx 36\%.$$

That is sufficient to operate the relay and cause an undesired tripping of the Bus breakers. This is incorrect operation of the Bus protection for external faults. One method to improve the reliability of operation during the transient period is to utilize a differential relay with multiple restraint coils.

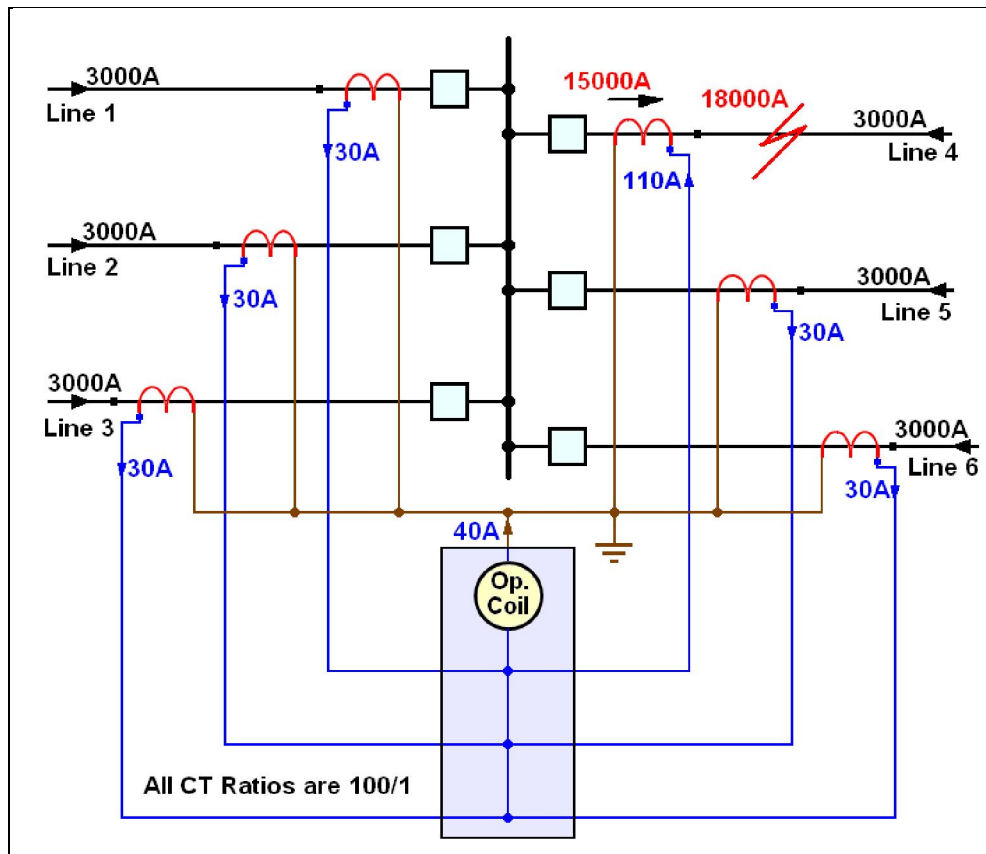


Fig. 1.2-8 Bus Differential Protection with Restraint Coils
for Close-In External Line Fault (CT on Line 4 in Saturation)

EXAMPLE 1.2-1

In Fig. 1.2-9 for Bus Differential Protection with Restraint Coils and Close-In External Line Fault, as shown, have all CTs with 100:1 turn's ratio. Each line is feeding 4,000A into the Bus and 20,000A out from the Bus through line 4 to supply the fault current. Determine the following:

- Total Fault Current.
- Currents in each of five CT secondary on lines 1, 2, 3, 5, and 6.

- iii) Ideal fault CT secondary current in line 4, assuming no saturation during external fault.
- iv) Assuming 160A flowing in fault CT secondary, the difference restraint current _____ Amps, proportional to total restraint current _____ Amps, is passing through the operating coil of the relay.
- v) Percentage Differential.

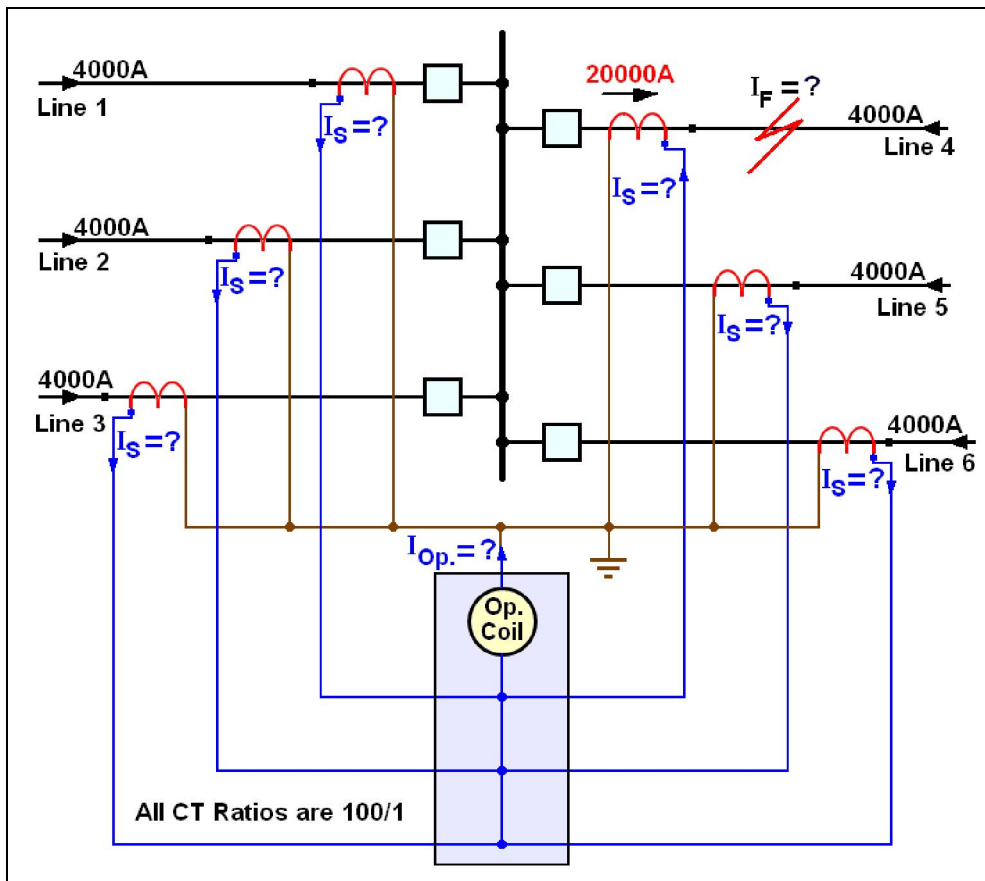


Fig. 1.2-9 Bus Differential Protection with Restraint Coils
for Close-In External Line Fault (CT on Line 4 in Saturation)

SOLUTION

- i) Total Fault Current = 20,000A + 4,000A = 24,000A
- ii) Currents in each of five CT secondary on lines 1, 2, 3, 5, and 6.
 $I_1 = I_2 = I_3 = I_5 = I_6 = 40A$
- iii) I_4 Ideal Fault CT secondary current, for $n_i = 100:1 = 20,000/100 = 200A$

iv) Assuming 160A, flowing in fault CT secondary, the difference restraint current 40A, proportional to total restraint current 160A, is passing through the operating coil of the relay.

v) Percentage differential = $(40\text{A}/160\text{A}) \times 100 \approx 25\%$

In order to allow high speed tripping and avoid misoperation during the first few cycles of the fault, the percentage differential would be set to about 50%. The multi-restraint relay being quite fast acting operates within 50-100 ms, approximately, corresponding to 3 to 6 cycles.

In order to improve accuracy, it is important that the burden on CTs be kept as low as possible. Therefore, CTs should not be used for any other purpose. For the same reason, the leads connecting the CTs should be of higher current carrying capacity.

As all of the CT ratios are normally identical, the Bus Differential Relays are not fitted with ratio taps. If a particular circuit does have a different CT ratio, then it is necessary to connect an auxiliary CT in order to match the others.

BUS TOTAL DIFFERENTIAL RELAYING

As shown in simplified form of Fig. 1.2-10, Bus Total Differential Relaying is used to clear a fault on the bus. The protected area includes, all equipment on the bus-side of the Current Transformers used in the total differential protection scheme.

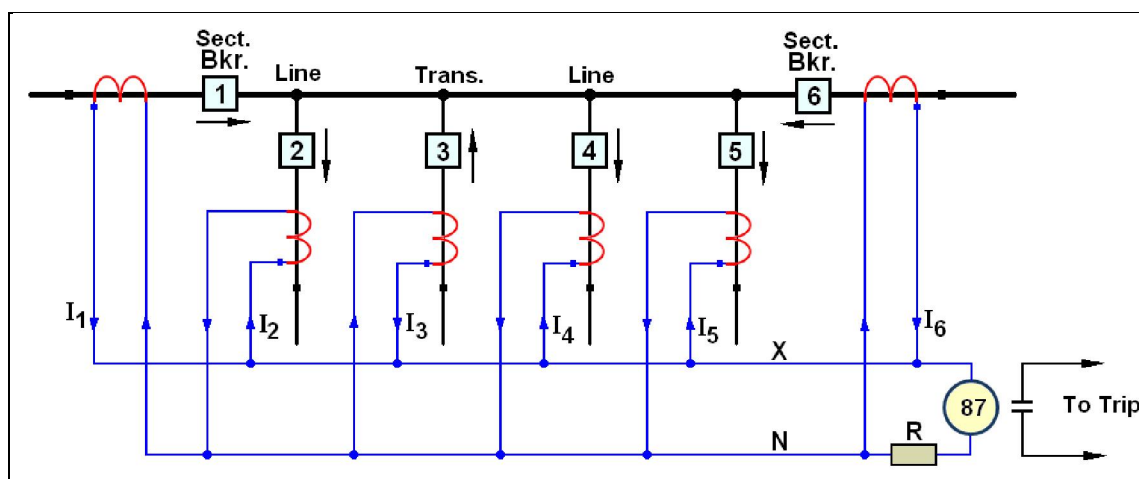


Fig. 1.2-10 Simplified Bus Total Differential Protection Scheme

The Current Transformers are usually located on the transformer side of the transformer breaker, on the opposite side of each section breaker and on the line side of each line breaker. The output currents of all the CTs on the same phase are collected by connecting together all like polarities of the Current Transformers. If the power flow from the Bus is equal to the power flow into the bus, conditions are normal and no current flows through the Differential Relay (87) connected across the parallel group of CT.

Secondary currents I_1 , I_3 , and I_6 flow into current bus X, and currents I_2 , I_4 , and I_5 flow out from current Bus X. Normally, the sum of the currents flowing in, is equal to the sum of the currents flowing out and no current flows through Relay (87). The power flow through one or both section breakers may not be towards the Bus but away from the bus. In such a case, secondary Current I_1 and/or I_6 will be reversed flowing away from current Bus X. Current balance will be maintained by an increase in transformer current I_3 and possibly an increase in current from a section breaker if one is feeding into the Bus while the other section breaker is feeding out. Again, no current will flow through the Relay (87). If a fault occurs outside of the protected area on a line or adjacent Bus, for example, the currents flowing into current bus X still equals the currents flowing out and Relay (87) will not see the fault. A fault within the protected area, defined by the Current Transformers, will cause a great increase in power flow into the area from the transformer and the two adjacent buses. Lines with sources of back-feed will also contribute to power flow into the fault. The decrease in Bus voltage at the time of fault will reduce to near-zero, the outputs on radial lines. The flow of secondary currents into current bus X will be increased greatly, whereas the flow of currents from current bus X will be very small or zero. The relay current will be equal to the difference between these currents.

Bus Total Differential Relays are usually set for comparatively low values of current and for very fast or instantaneous operation. Other relays may be connected in series with the Relay (87) to perform other functions such as fault detection. In some cases, there may be a “sensitive” Differential Relay connected in series with the Instantaneous Differential Relay.

The “sensitive” relay operates at lower values of current and has an Inverse Time-Delay. This relay detects high-impedance Bus faults that would not operate the higher-set Instantaneous Differential Relay. Other protective relays may also be connected into parts of the total differential scheme to perform separate protective functions such as; overload tripping on a section breaker and partial Bus differential relaying etc.

Resistor R is used to limit the flow of current through Relay (87) and thus prevent Relay (87) operation under abnormal current balance conditions. This may occur when heavy fault current flows through a set of Current Transformers into an external fault. The heavy current may cause saturation of the Current Transformers and they may deviate enough from their true ratio to cause an unbalance or residual current to flow through Relay (87). The resistor will keep this current below the pick-up value of the relay, but it will not interfere with the relay operation for the higher values of current that are encountered with an internal fault.

BUS PARTIAL DIFFERENTIAL RELAY PROTECTION

Bus Partial Differential Relaying, in its simplest form of application, combines the Current Transformer secondary currents of the feeds to a bus and then measures this resultant current where it enters into the Current Transformers of the load positions. Bus Partial Differential Relaying is usually a part of the total Bus differential scheme. The partial scheme acts as a back-up for internal Bus faults and for external line faults that are not cleared by first-line relaying.

Fig. 1.2-11 shows the current transformer secondaries of the section breakers and the power transformer connecting to partial bus XP. Currents I_1 , I_3 and I_6 flow into Bus XP and combine to form Current I_p . Current I_p flows through the Partial Differential Relay (X-87P) into current Bus XT and then flows out from Bus XT as the divided line Currents I_2 , I_4 and I_5 . No current flows through relay X-87B. A neutral or Ground Partial Differential Relay (N-87P) is used in addition to the three-phase relays. The phase relays are set at a comparatively higher current with an Inverse Time-Delay.

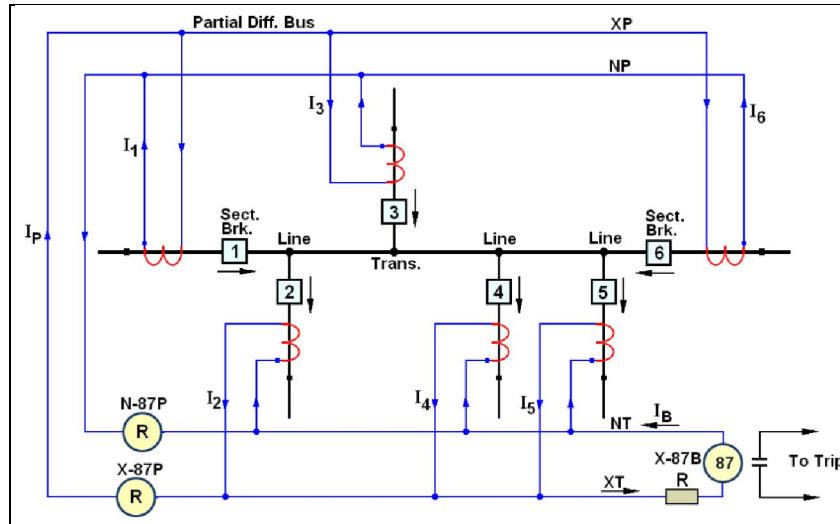


Fig. 1.2-11 Partial and Total Bus Differential Protection Scheme

Since X-87P measures all current flowing into Bus XT, any X-phase fault on a line will be seen by X-87P. If the line relays or breaker controls fail to open the breaker within the required time, relay X-87P will trip the feeds to the bus.

Under the same condition, Total Differential Relay X-87B will not see the fault because the CT on the line in trouble will maintain balance of currents.

$$I_P = I_1 + I_3 + I_6$$

$$I_P - (I_2 + I_4 + I_5) = 0 = I_b$$

In the event of a Bus fault within the area defined by the CT's, the currents I_1 , I_3 and I_6 will combine and their resultant current I_P will flow into current Bus XT. The line currents I_2 , I_4 and I_5 will be greatly reduced by the decrease in voltage on the faulty bus. The current I_P flowing into Bus XT will be much greater than the sum of the currents I_2 , I_4 and I_5 flowing out of Bus XT. The difference in currents (I_P) will flow through X-87B. Since the Total Differential Relay (X-87B) is set lighter and faster than the Partial Differential Relay, it will operate first and trip all breakers on the bus.

PARTIAL DIFFERENTIAL BUS PROTECTION (ADJACENT BUS FAULT)

A fault on an adjacent bus or in the transformer will not be seen by the Partial Differential Relays in Fig. 1.2-12, because the fault current components in the CT

circuits of the Bus feeds will balance out when they combine at the Partial Differential Bus XP.

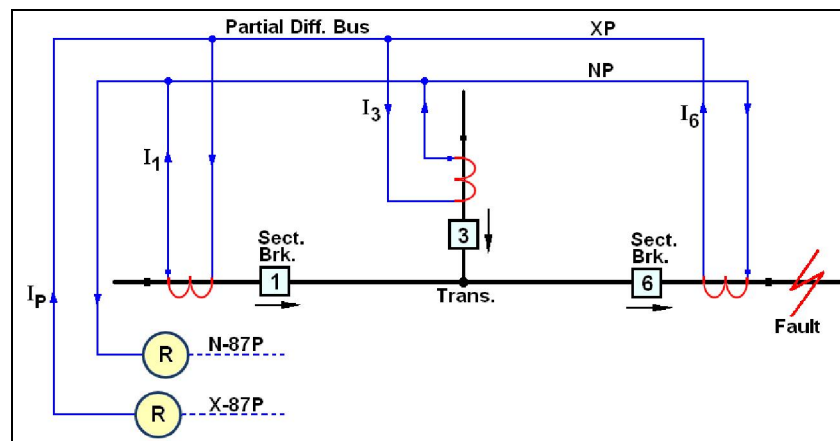


Fig. 1.2-12 Partial Differential Bus Protection (Adjacent Bus Fault)

Current I_1 and I_3 combine at Bus XP and flow out as currents I_6 and I_p . The current I_p through the Partial Differential Relay X-87P represents only the total load of the lines and this load is greatly decreased by the reduced voltage at time of fault.

$$I_p + I_6 = I_1 + I_3.$$

The fault on the adjacent Bus will be cleared by the operation of differential relays on that section of the bus. This will include tripping section Breaker 6. Likewise, a fault in the transformer or on the primary side of the transformer will be cleared by the transformer protective relays tripping out Breaker 3.

SELECTIVE PARTIAL BUS DIFFERENTIAL PROTECTION

Selective Partial Differential Bus relaying provides Bus differential protection and also Back-Up Relay Protection for each breaker position on the bus. On line back-up operation, this scheme will function on fault currents that are too low to operate the regular Partial Differential Relays. Auxiliary Current Transformers are usually employed in selective partial schemes to provide ratios that will give matching currents from all breaker positions and to provide isolation of the Selective Partial Relays from the other Bus Differential Relays. A simple three-position selective partial protection scheme is shown in Fig. 1.2-13.

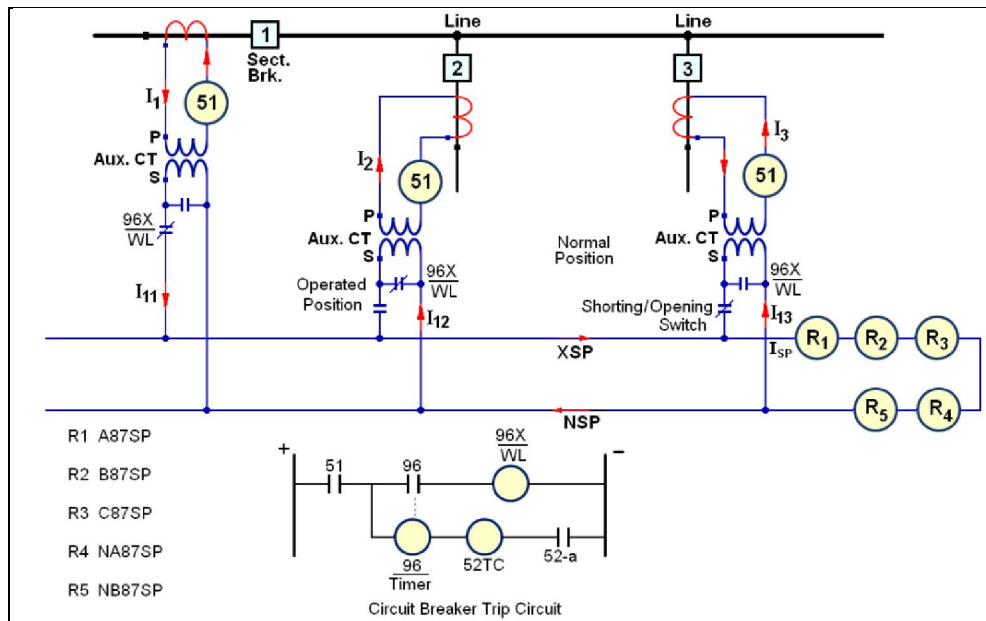


Fig. 1.2-13 Selective Partial Differential Bus Protection

Sensitive monitor relays can be employed with the selective partial scheme to provide early detection of current transformer or current wiring defect before protection becomes defective.

In Fig. 1.2-13, the middle 96X is shown in the operated position, which short-circuits the secondary of the auxiliary CT and disconnects it from current Bus XSP. Referring to trip circuit in the diagram, this is the position 96X would take if the breaker had failed to open on a line fault and Timing Relay (96) had closed its contacts in the coil circuit of 96X.

Assuming a ground fault on the line, the secondary current I_{12} will circulate through the shorting contacts of 96X (WL) and will not accept current from current Bus XSP. Currents I_{11} and I_{13} will combine to produce Current I_{SP} , which flows through relays A87SP, B87SP, C87SP, NB87SP and NA87SP. Relay C87SP is the Sensitive Monitor Relay, which is used to detect current unbalances under normal load conditions.

It does not perform tripping, but causes a station alarm. Relays B87SP and N87SP are Instantaneous Fault Detector Relays whose contacts are in series with their respective Time-Delay Relays. Time-Delay Relay A87SP is adjusted for phase-to-phase faults. Time-Delay Relay NA87SP is set at a lower value of current to measure the neutral or residual current, which occurs on ground faults.

The Selective Partial Scheme will function as a Total Differential Scheme on any Bus fault within the boundary of the Current Transformers. The operation of secondary currents will be similar to that described in Bus Total Differential Protection. However, there will be a time-delay in the selective partial scheme, whereas the regular total differential scheme is instantaneous in operation.

SUMMARY

- The two essential requirements for Busbar Protection are speed and stability to account for the overall power system safety and reliability.
- Bus bar protection is primarily concerned with:
 - i) Limitation of consequential damage.
 - ii) Removal of Bus faults in less time than could be achieved by back-up line protection to maintaining system stability.
- Complete fault clearance may be obtained in approximately 0.1 second corresponding to 6 cycles at 60 Hz.
- In order to maintain high order of integrity needed for Bus protection, it is an almost invariable practice to make tripping depend on two independent measurements of fault quantities.
- Substation Bus Protection is most universally accomplished by differential relaying.
- The double donut CTs mounted on a common primary conductor for the total Differential Bus Protection before tripping must provide the degree of selectivity necessary to differentiate between an internal and an external fault.
- The linear coupler scheme provides extremely reliable Bus protection where the iron core is replaced by an air cored transformer to eliminate core saturation.
- The major problem with Bus Differential Protection is the unequal core saturation of the Current Transformers used in the system due to the large variation of current magnitude and residual flux in the individual transformers used in the system, particularly during a fault.

- The three most common methods of solving the Bus Differential Protection problems are:
 - a) Eliminating iron in the Current Transformer as in Linear Coupler System.
 - b) Using multi-restraint variable percentage Differential Relay specifically designed to be insensitive to DC saturation.
 - c) High impedance voltage operated Differential Relay with a series resonant circuit to limit sensitivity to the DC component.
- The linear couplers (unlike Current Transformers) can be safely open-circuited making them less hazardous to electric shock.
- For an internal Bus fault using linear coupler for each line for Bus Differential Protection, each coupler will contribute its output voltage to the relay depending on individual primary circuit current giving total sum of volts across the relay operating coil and the relay will trip.
- In Bus Differential Protection with Current Differential Circuit (Balanced Loads) using identical CT ratios, the secondary currents cancel out with no current passing through the relay operating coil because the incoming and outgoing currents at the relay are equal.
- In Bus Differential Protection with Current Differential Circuit (Internal Fault), all secondary currents are additive, so that resultant output current passing through the relay operating coil would trip all the Bus breakers.
- In Bus Differential Protection with Close-In Line Fault, if the CT on the line with external fault is over its saturation limit, the relay may operate incorrectly, as the level of current in the faulty line may be 30 times its rating.
- The Selective Partial Differential Bus Protection Scheme will function as a Total Differential Scheme on any Bus fault within the boundary of the Current Transformers.

FORMULA

$$I_R = \frac{E_{\text{sec.}}}{Z_R + \sum Z_C} = \frac{I_{\text{prim}} \times M}{Z_R + \sum Z_C}$$

Where:

I_R = Current in linear coupler secondaries in series with relay

E_{SEC} = Voltage induced in linear coupler secondary

I_P = Primary current rms symmetrical

M = Mutual reactance = 0.005Ω for 60 cycles

Z_C = Self impedance of linear coupler secondary

Z_R = Impedance of relay

GLOSSARY

Pertaining:	Be appropriate, relate
Paraamount:	Supreme

REVIEW EXERCISE

Complete the following statements:

1. The two essential requirements for Busbar Protection are _____ and _____ to account for the overall system safety and reliability.
2. The modern differential Busbar Protection schemes use either _____ biased or _____ unbiased relays capable of operating within _____ timing at a very moderate multiple of fault setting
3. List the three reasons of dangers that may exist in practice for the complete stability of a correctly applied protective system:
 - i) _____

 - ii) _____

 - iii) _____

4. Substation Bus Protection is most universally accomplished by _____.
5. The CTs saturation problem in Bus Differential Protection due to high current magnitude and residual flux can be overcome by _____ in the operating circuit of the relay.
 - a) Optical couplers or by stabilizing resistors b) Linear couplers or by stabilizing resistors
 - c) Linear amplifiers or by stabilizing resistors d) Linear couplers or by stabilizing regulators
6. The DC saturation is much more severe than AC saturation where a small amount of DC from an asymmetrical fault wave may saturate the transformer core and appreciably reduce the secondary output below the actual rating.
 - a) True b) False

7. In Fig. 1.2-14 for an internal Bus fault using four linear couplers for Bus Differential Protection: Linear Coupler Output = 5V/1000 Amps
- Lines 1, 2, 3 and 4 coupler outputs during the internal fault are __, __, __, and __V, respectively.
 - Each coupler will contribute its output voltage to the relay depending on individual primary circuit current giving a total of $V_R = \underline{\hspace{2cm}}$ volts across the relay operating coil and the relay will trip.

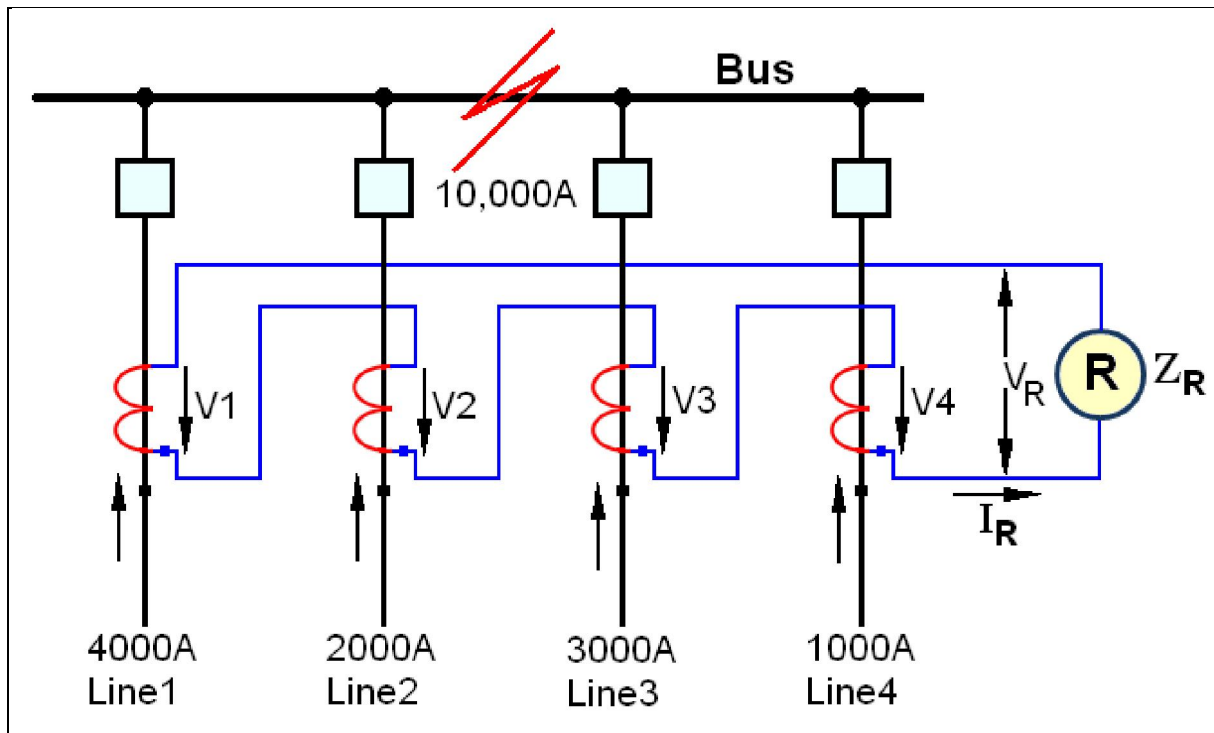


Fig. 1.2-14 Bus Protection using Linear Couplers (Internal Fault)

- 20
 - 30
 - 40
 - 50
8. In Fig. 1.2-15 typical Four-Circuit Bus Protection using Linear Couplers during an external fault, the relay would not trip, because of __ volts across its coil.

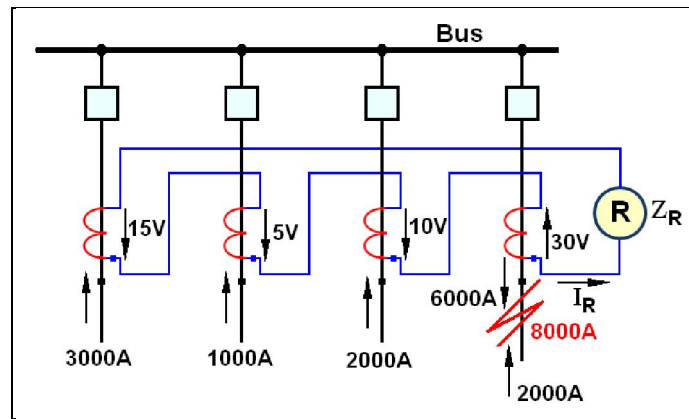


Fig. 1.2-15 Bus Protection using Linear Couplers (External Fault)

- | | |
|-------|-------|
| a) 30 | b) 20 |
| c) 0 | d) 40 |

9. In Fig. 1.2-16 for Typical Bus Differential Protection with Current Differential Circuit, when the loads are balanced the relay current is _____ Amps, assuming CT ratios are 100:1.

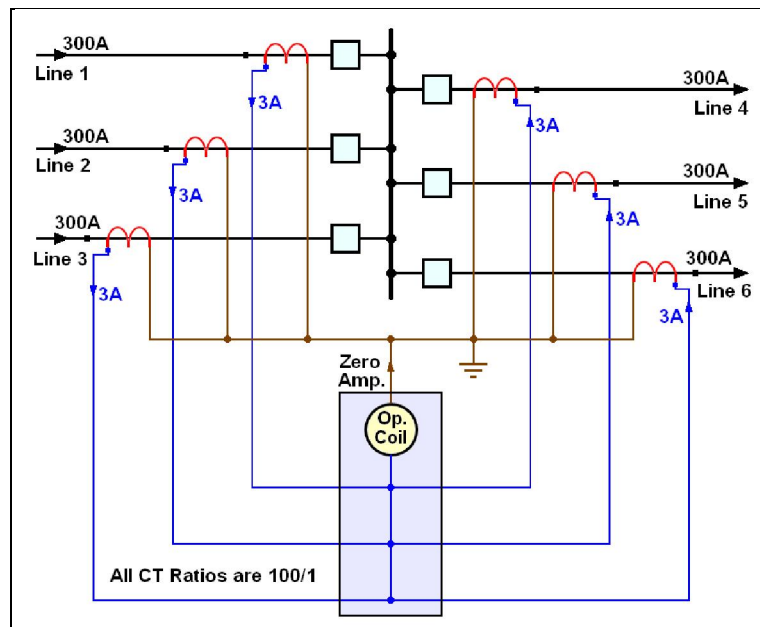


Fig. 1.2-16 Bus Differential with Current Differential Circuit (Balanced Loads)

- | | |
|------|------|
| a) 0 | b) 6 |
| c) 3 | d) 9 |

10. In Fig. 1.2-17 for Typical Bus Differential Protection with Current Differential Circuit (Internal fault):

- i) The CTs' secondary currents are all _____ so that 180 Amps passing through the relay coil would trip all the Bus breakers.
- ii) If the CTs were to saturate for a Bus fault, would misoperation occur and Why?

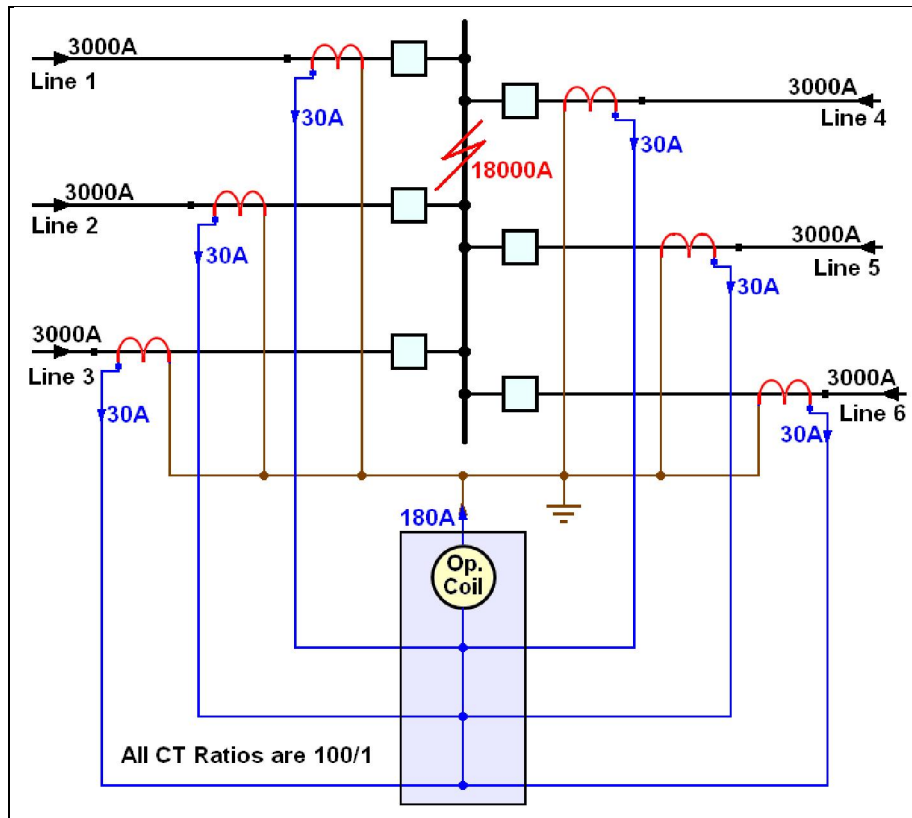


Fig. 1.2-17 Bus Differential Protection with Current Differential Circuit

11. In Fig. 1.2-18 for Typical Bus Differential Protection with Close-In Line Fault, why would the relay likely misoperate?

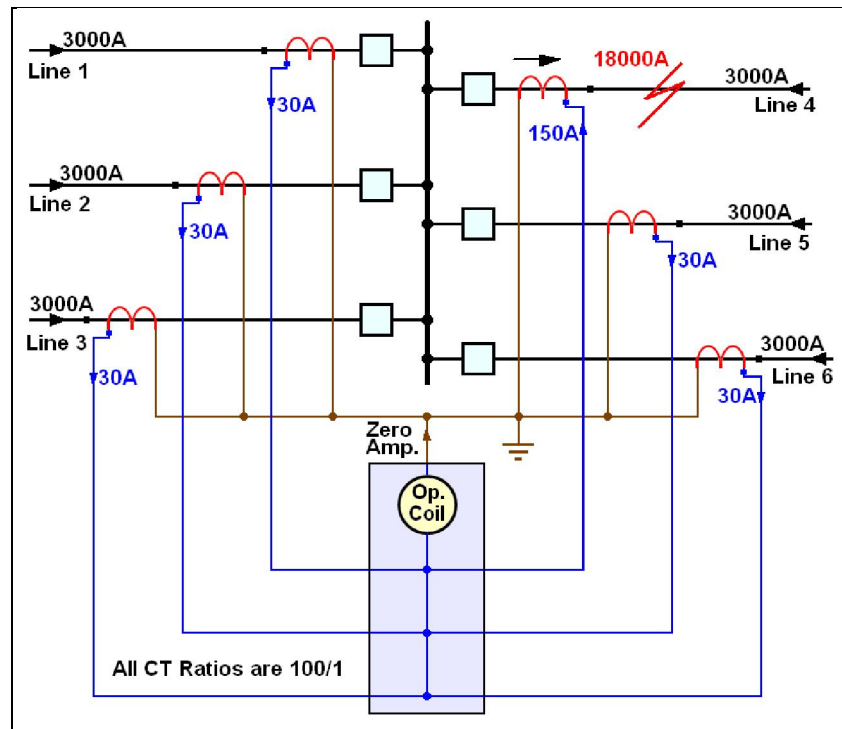


Fig. 1.2-18 Typical Bus Differential Protection with Close-In Line Fault

12. In Fig. 1.2-19 for Bus Differential Protection with Restraint Coils and Close-In External Line Fault:

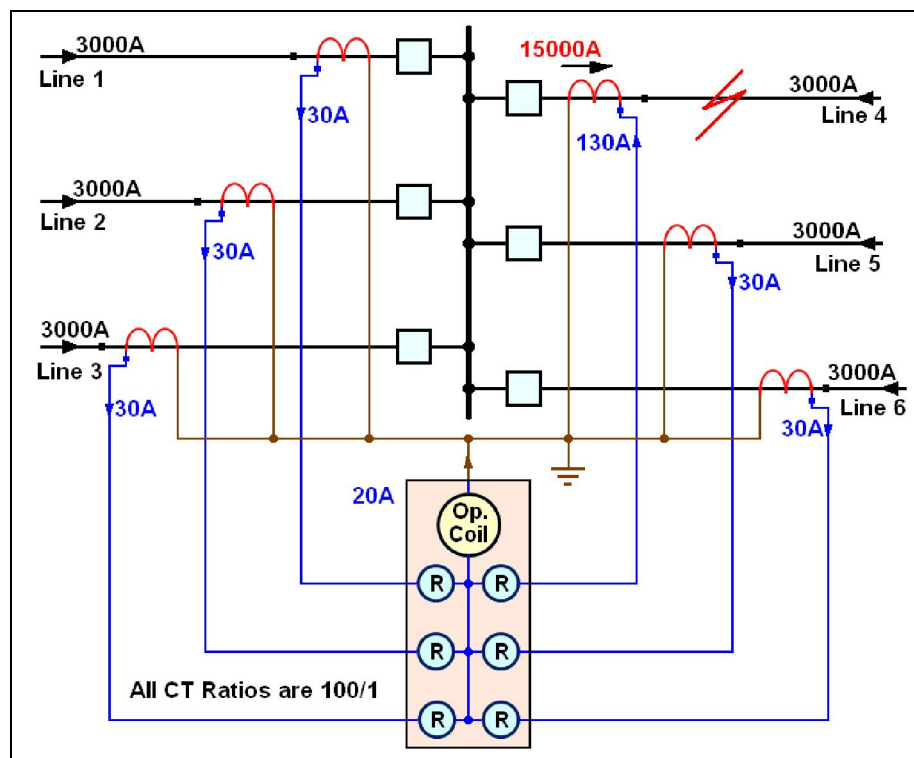


Fig. 1.2-19 Bus Differential Protection with Restraint Coils for Close-In Line Fault

- i) what is the function of the multi-restraint coils in the relay?
 - ii) In order to improve tripping accuracy, the burden on CTs is not important.
 - a) True
 - b) False
 - iii) In order to improve tripping accuracy:
 - a) The burden on CTs should be kept as low as possible and be not used for other purposes.
 - b) The leads connecting the CTs should be of higher current carrying capacity.
 - c) All of the CT ratios should be identical, unless an auxiliary CT is installed in order to match the others.
 - d) All of above
 - iv) With 30 Amps current flowing in each CT secondary and 15,000 Amps close-in fault current from the Bus, the external fault current is _____ Amps.
 - a) 12,000
 - b) 18,000
 - c) 15,000
 - d) 21,000
 - v) Assuming CT4 secondary drawing 130A instead of 150A due to saturation, resulting in 20A through the operating coil, the percentage differential is, approximately, _____.
 - a) 15
 - b) 30
 - c) 20
 - d) 25
13. Given Fig. 1.2-20 for the bus total differential protection scheme, partially drawn:
- i) Complete the CT connections for the Total Differential Protection.
 - ii) Normally, the sum of the currents flowing in is equal to the sum of the currents flowing out and no current flows through Relay (87).
 - a) True
 - b) False

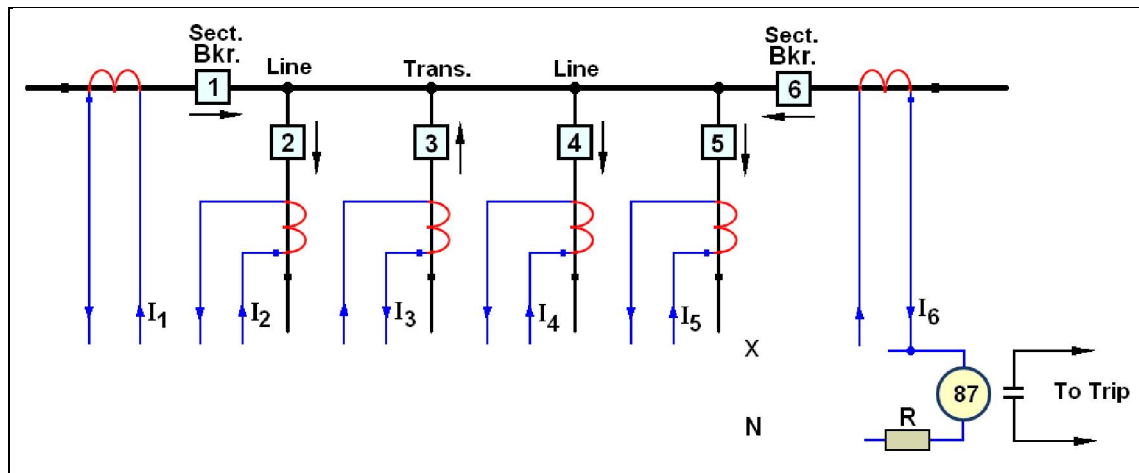
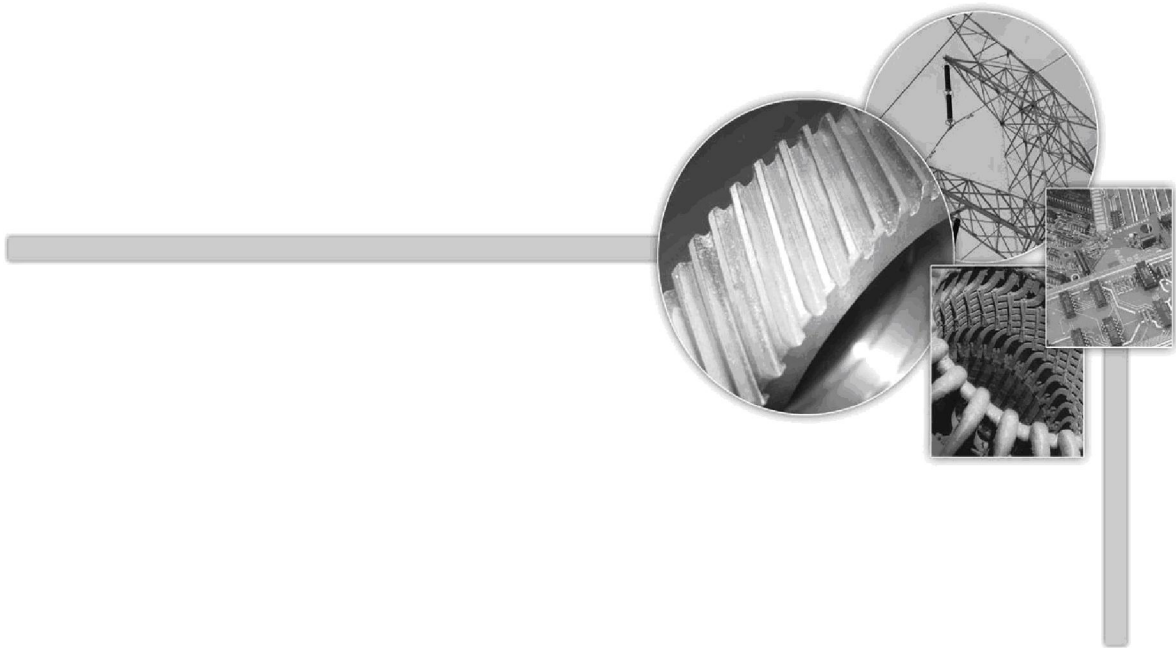


Fig. 1.2-20 Simplified Bus Total Differential Protection Scheme

Read the following statements, then select True or False:

Statement	T	F
i) Selective partial differential Bus relaying provides Bus differential protection and back-up relay protection for each breaker position on the bus.		
ii) If the fault current is symmetrical, a DC component is present.		
iii) The partial Bus differential scheme acts as a backup for internal Bus faults and for external line faults that are not cleared by first-line relaying.		
iv) Bus Total Differential Relaying is used as a backup for Selective Partial Differential Bus Relaying.		
v) The linear coupler for Bus protection uses the iron core instead of the usual Current Transformer.		
vi) Auxiliary Current Transformers are usually employed in selective partial schemes to provide ratios that will give matching currents from all breaker positions and to provide isolation of the Selective Partial Relays from the other Bus Differential Relays.		



LESSON 1.3

BUS BAR PROTECTION BY HIGH IMPEDANCE DIFFERENTIAL RELAYS

LESSON 1.3

BUSBAR PROTECTION BY HIGH IMPEDANCE DIFFERENTIAL RELAYS

OVERVIEW

This lesson discusses the requirements for correct applications of High Impedance Differential Relays. It gives examples for Bus bar protection and describes the importance of supervisory circuit for checking bus differential faults.

The lesson also scopes out the operation of local breaker failure protection for ring Bus and breaker and half bus protection.

OBJECTIVES

Upon completion of this lesson, the trainee will be able to:

- List the requirements for correct application of high impedance differential relay Protection scheme.
- Demonstrate busbar protection using high impedance relays.
- Identify supervisory circuit for checking Bus differential protection.
- Demonstrate a typical single-line, single-breaker bus and its DC schematic diagram.
- Identify the breaker-failure/local back-up operation diagrams for ring bus and breaker and half bus protection.

INTRODUCTION

For Buses with a large number of circuits, the High Impedance Differential Relay offers the simplest and most effective Bus Protection. The most essential requirements for correct application of High Impedance Differential Relay Protection Scheme are:

- Equal CT ratios
- Low CT secondary winding resistance
- Adequate knee-point voltage output from the CTs
- Low lead burden

High-speed differential Bus protection is often provided by the use of High Impedance Relays, which are designed to eliminate the problem of CT saturation, as shown in Fig. 1.3-1. A resonant circuit is connected in series with the relay operating coil.

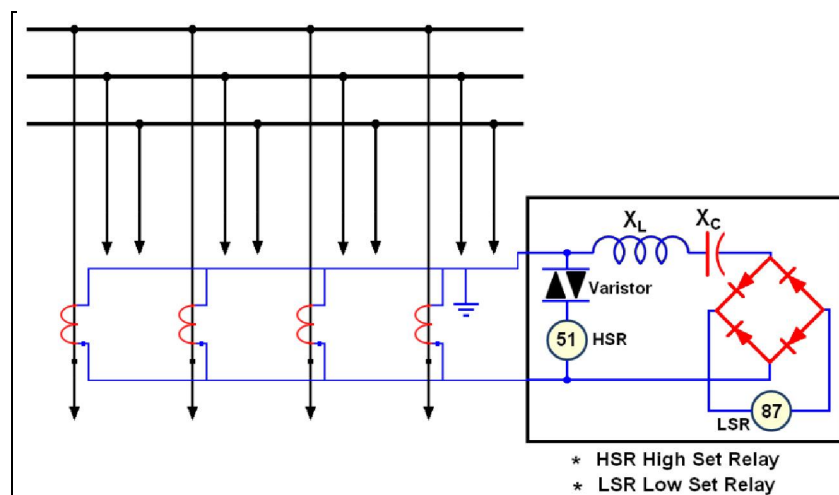


Fig. 1.3-1 High Impedance Differential Relays (Only Phase A shown)

The resonant circuit consists of a capacitor and reactor, which are tuned to allow the passage of 60 Hz current only. It effectively filters out any harmonics and DC components causing wave distortion during the initial transient. One problem with this arrangement is that, when the setting of the relay coil is adjusted, it changes the inductance in the circuit and thus changes the resonant frequency. In order to avoid this, a rectifier is placed in the circuit so that only DC current is fed to the relay operating coil.

The effect of the rectifier and the resonant circuit raises the total impedance across the relay to about $2,500\Omega$. This impedance is much greater than the impedance of the CTs, which is probably about 2Ω or less. Any error current existing, as a result of unequal saturation or different CT characteristics, will flow through the CTs rather than through the High Impedance Relay circuit. To allow the correct distribution of this error current, it is important that the resistance in each of the CTs be equal and as low as possible up to the junction point.

When there is an internal fault on the bus, all of the circuits will feed into the Bus and, therefore, all of the secondary currents will be additive. In this situation, all of this current must flow through the differential relay and operate the tripping circuit. An out of balance current, say 20A, flowing through the CT circuit, which has an impedance of, say 3Ω , would produce a voltage of 60 volts across the Impedance Relay. For this condition, the relay tripping would be set at 60 volts. However, this does raise another problem. If all of 20 Amp current were to pass through the High Impedance Relay of $2,500\Omega$, the total voltage drop across the relay would be 2,500 times 20 or 50kV. This would obviously damage the relay. This problem is resolved by placing a parallel circuit across the relay so as to by-pass most of the current. The by-pass circuit consists of a Varistor (two back-to-back Zener diodes).

Advantage is taken of this feature to provide further protection. An instantaneous over-current relay is installed in series with the Varistor. This relay is set to operate instantaneously for very high levels of differential fault current. A range of pick-up current settings is available from 2A up. This is a plunger type relay, which will trip within about 8 ms that is less than about $\frac{1}{2}$ cycle giving extremely high speed operation.

Light Bus faults are cleared by the High Impedance Relay within 20 ms, that is about $1\frac{1}{2}$ cycles. This is also fast operation. The setting of the High Impedance Relay is achieved by selecting the correct voltage tap in the range of 50-500 volts. The relay pickup voltage is determined, as follows.

For an external fault, the CT in the faulted line may saturate. A CT voltage is the product of the current from the source CT times the resistance of the windings and leads of the saturated CT. The CT voltage develops across the Bus Differential Relay.

The, worst case, highest saturation voltage developed across the relay may be 100 volts. If the relay must not trip at 100 volts, we would desensitize the relay by setting it with a safety factor of two (i.e 200 volts). The safety factor would have little effect for internal Bus faults.

Fig. 1.3-2 shows a supervisory circuit, which allows the operator to check the integrity of the high impedance Bus differential protection circuit by applying a low voltage of about 40V. When on standby, contact A is closed and the 40 volts test voltage is available that should not be enough to operate the relay. Contact B is closed to check for short circuits. A short in the CTs or the Relay (87) causes the voltage to fall. To check for open circuits, leave contact B closed and open contact A. If there is an open circuit in the CT, a voltage will be present. The indicated voltage should be zero if the circuit is OK.

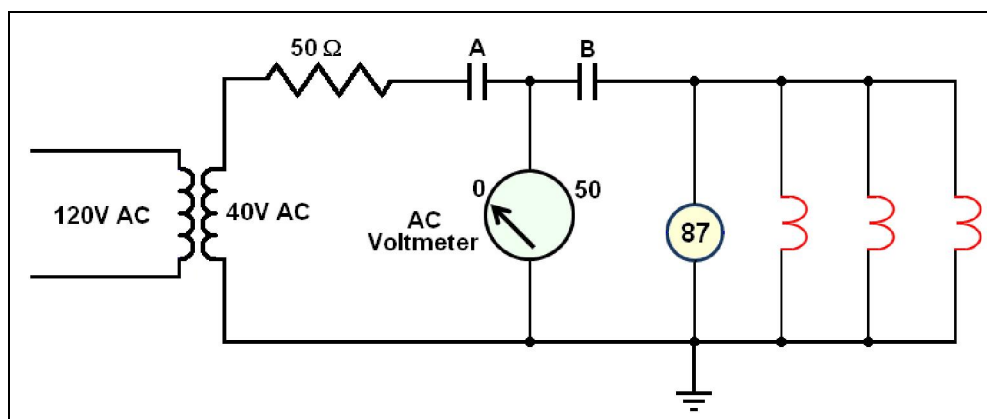


Fig. 1.3-2 Supervisory Circuit for checking Bus Differential Protection

LOCAL BREAKER FAILURE PROTECTION

Local back-up breaker failure protection is characterized by fault detection and initiation of tripping at the local terminal. For example, in Fig. 1.3-3, a fault on line HR may not be properly cleared by the primary protection system because of a failure in any part of the system other than the circuit breaker. In that case, the secondary relaying system will detect the fault and trip Breaker 2.

If the fault on line HR is not properly cleared because of a failure of breaker 2, the primary or secondary protective relays will initiate local breaker failure back-up and

open breakers 3, 4 and 5 at Bus H. For effective local back-up protection, there must be at least two relatively independent protective systems to cover all the lines or equipment being protected.

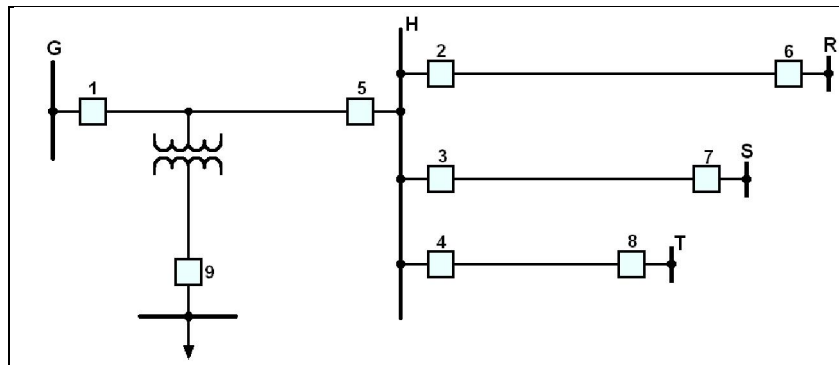


Fig. 1.3-3 Local Breaker Failure Protection

For breaker failure, however, only one protective system is required, even though the protection is initiated by both the primary and the secondary relaying systems. Instantaneous Relays are considered as an independent protective system.

BREAKER FAILURE PROTECTION APPLICATION

It is recommended that:

1. One breaker-failure circuit per breaker be applied regardless of the Bus configuration.
2. All adjacent breakers be tripped regardless of fault location.

One timer per Bus or one timer per breaker may be used. The latter is recommended, since it provides maximum isolation and flexibility, even though it does involve additional timers. These methods will be illustrated for various Bus arrangements.

SINGLE-LINE, SINGLE-BREAKER BUS PROTECTION

A typical Single-Line, Single-Breaker Bus, is shown in Fig. 1.3-4.

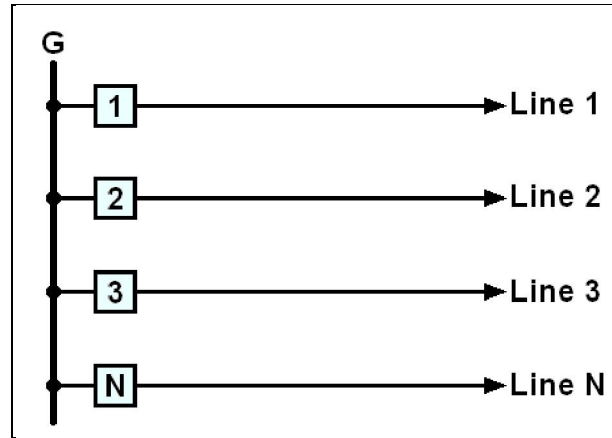


Fig. 1.3-4 Single-Line Single-Breaker Bus

TWO METHODS OF SINGLE-LINE SINGLE-BREAKER BUS PROTECTION

The two methods of protection are:

- One timer per Bus
- One timer per breaker

Fig. 1.3-5 shows the simplified DC schematic for local back-up protection on breaker failure using a common timer for a Single-Line Single-Breaker Bus.

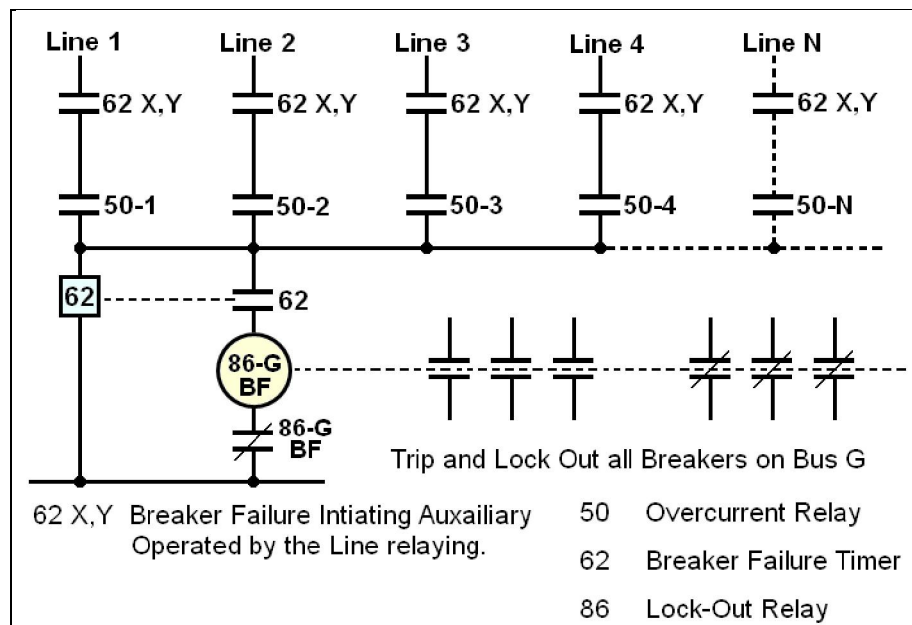
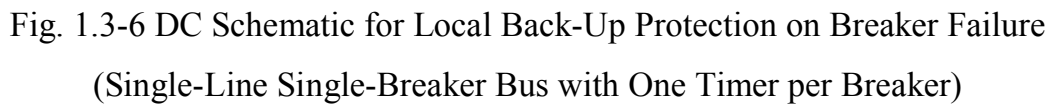


Fig. 1.3-5 DC Schematic for Local Back-Up Protection on Breaker Failure
(Single-Line Single-Breaker Bus with Common Timer)



One common timer per Bus is less costly than one timer per breaker method.

- Spreading fault may cause incorrect operation. If a line 1 fault spreads into line 2 with sequential operation of 62XY and 50 contacts, the common timer circuit may not be energized long enough to operate and trip all breakers, even though both lines 1 and 2 breakers may trip normal.
- The common timer must be set for the slowest breaker interrupting time.

- Each timer is de-energized as soon as the associated line fault is cleared.

- The separate timers permit to be set for the interrupting timers of the individual breakers.

PROTECTION OF RING BUS AND BREAKER AND A HALF

Typical Ring Buses and Breaker and a Half Buses are shown in Fig. 1.3-7 and Fig. 1.3-8, respectively. Tables 1.3-1 and 1.3-2, correspondingly, show all the adjacent breakers tripped regardless of fault location where the breakers that are already tripped, will be retripped for sake of reliability.

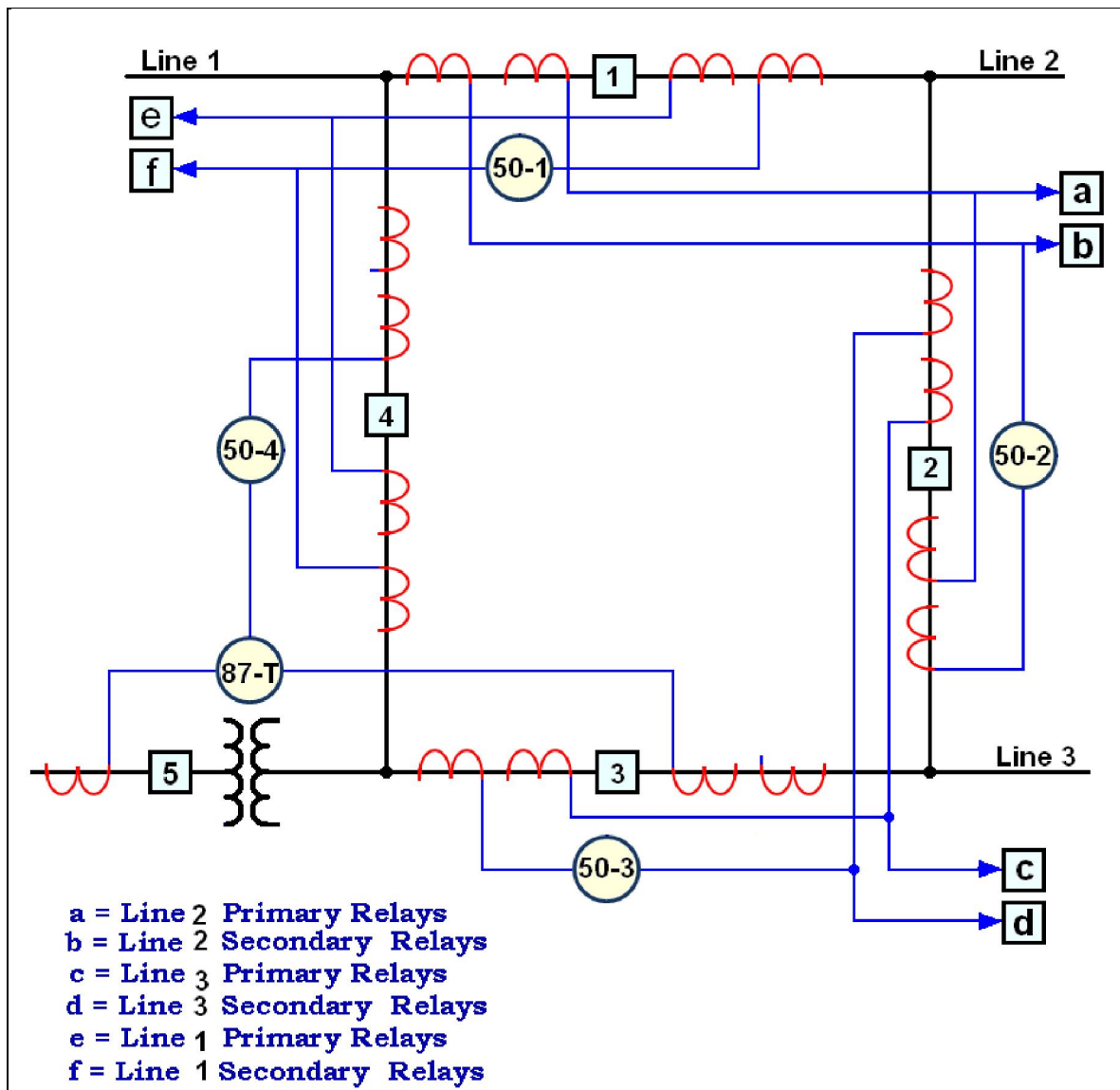


Fig. 1.3-7 Single-Line Diagram of Ring Bus

Local Back-up or Breaker Failure For CB No:	86 Relay Operations
1	Trip 2 and 4. Transfer-trip lines 1 and 2
2	Trip 1 and 3. Transfer-trip lines 2 and 3
3	Trip 2, 4, and 5. Transfer-trip line 3
4	Trip 1, 3, and 5 Transfer-trip line 1

Table 1.3-1 Breaker-Failure/Local Back-up Operations for Ring Bus

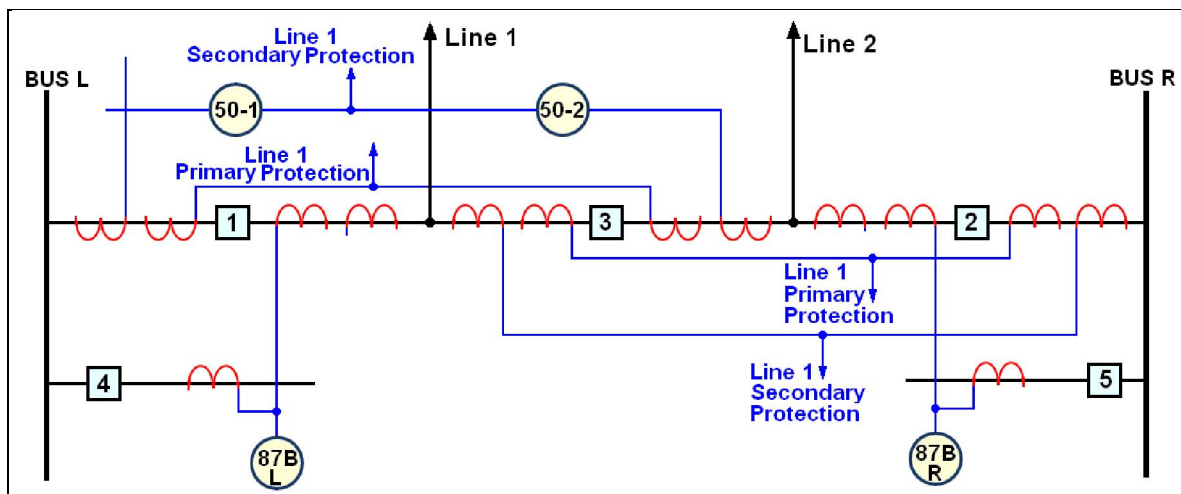


Fig. 1.3-8 Single-Line Diagram of Breaker and Half Bus

Local Back-Up or Breaker Failure For CB No:	86 Relay Operations
1	Trip 2 and all other Bus breakers, such as 4, etc on Bus L. Transfer trip line 1.
2	Trip 1 and 3. Transfer-trip lines 1 and 2.
3	Trip 2 and all other Bus breakers, such as 5, etc. on Bus R. Transfer-trip line 2.

Table 1.3-2 Breaker-Failure/Local Back-up Operations for Breaker and Half Bus

SUMMARY

- A resonant circuit in series with the operating coil of High Impedance Relay used for Bus Protection eliminates harmonics and DC components due to the CT saturation.
- The effect of the rectifier and the resonant circuit raises the total impedance across the relay to about $2,500\Omega$.
- In the worst case, if the highest CT saturation voltage must not trip the relay, we would desensitize the relay by setting it with a safety factor of two.
- For effective local back-up protection, there must be at least two relatively independent protective systems to cover all the lines or equipment being protected.
- Two methods of Single-Line Single-Breaker Bus protection are one timer per Bus and One timer per breaker.
- Advantages of One Timer per Breaker protection are:
 - Each timer is de-energized as soon as the associated line fault is cleared.
 - The separate timers permit to be set for the interrupting times of the individual breakers.

REVIEW EXERCISE

1. List the most essential requirements for correct application of High Impedance Scheme for Busbar Protection are:
2. The resonant circuit in series with the operating coil of High Impedance Relay used for Bus Protection consists of _____.
 - a) Capacitor and resistor
 - b) Inductor and resistor
 - c) Capacitor and reactor
 - d) R-L-C
3. The resonant circuit in series with the operating coil of High Impedance Relay used for Bus Protection is tuned to allow _____ Hz current to pass through and blocks any harmonics and DC components causing wave distortion.
 - a) 60
 - b) 120
 - c) 50
 - d) 30
4. In Fig. 1.3-9, an out of balance current, say 20 Amps, flowing through the CT circuit, which has an impedance of, say 2 Ohms, would produce a voltage of ----- volts across the Impedance Relay.
 - a) 20
 - b) 30
 - c) 40
 - d) 60

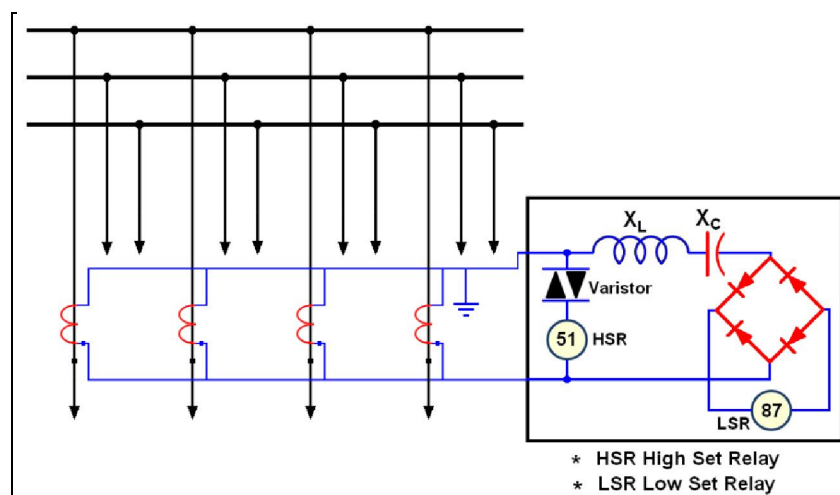


Fig. 1.3-9 High Impedance Differential Relays (Only Phase A shown)

5. Explain the purpose of High Set Relay in Fig. 1.3-9.
6. Heavy Bus faults cause the High Impedance Relay to operate in about _____ cycle while light Bus faults are cleared in about _____ cycles.
7. What is the function of the supervisory circuit in Fig. 1.3-10?

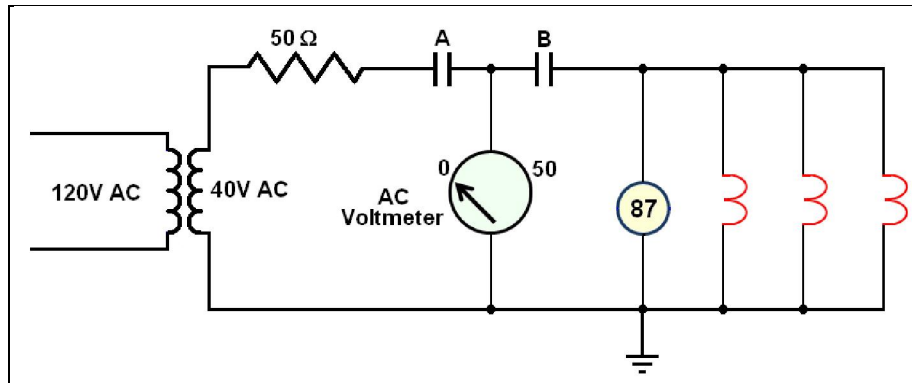


Fig. 1.3-10 Supervisory Circuit for checking Bus Differential Protection

8. In Fig. 1.3-11 for Local Breaker Failure Protection, if the fault on line HR is not properly cleared because of a failure of breaker 2, the primary or secondary protective relays will initiate _____ failure back-up and open breakers __, __, and __ at Bus H.

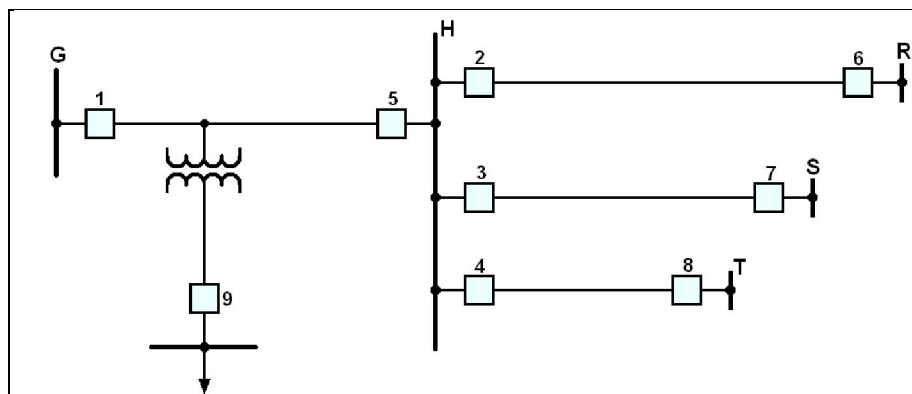


Fig. 1.3-11 Local Breaker Failure Protection

9. For breaker failure protection, only one protective system is required, even though the protection is initiated by both the primary and the secondary relaying systems.
 - a) True
 - b) False

REVIEW EXERCISE

10. For breaker failure protection, one timer per breaker is recommended, since it provides maximum _____ and _____.
11. Fig. 1.3-12 shows simplified DC schematic for local back-up protection on breaker failure using _____ timer(s) per breaker for the Single-Line Single-Breaker Bus.

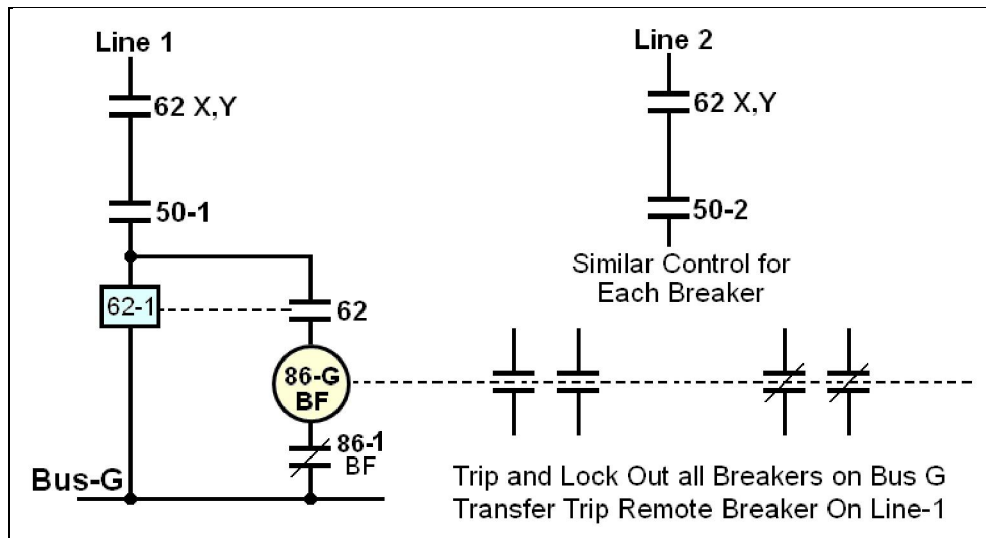
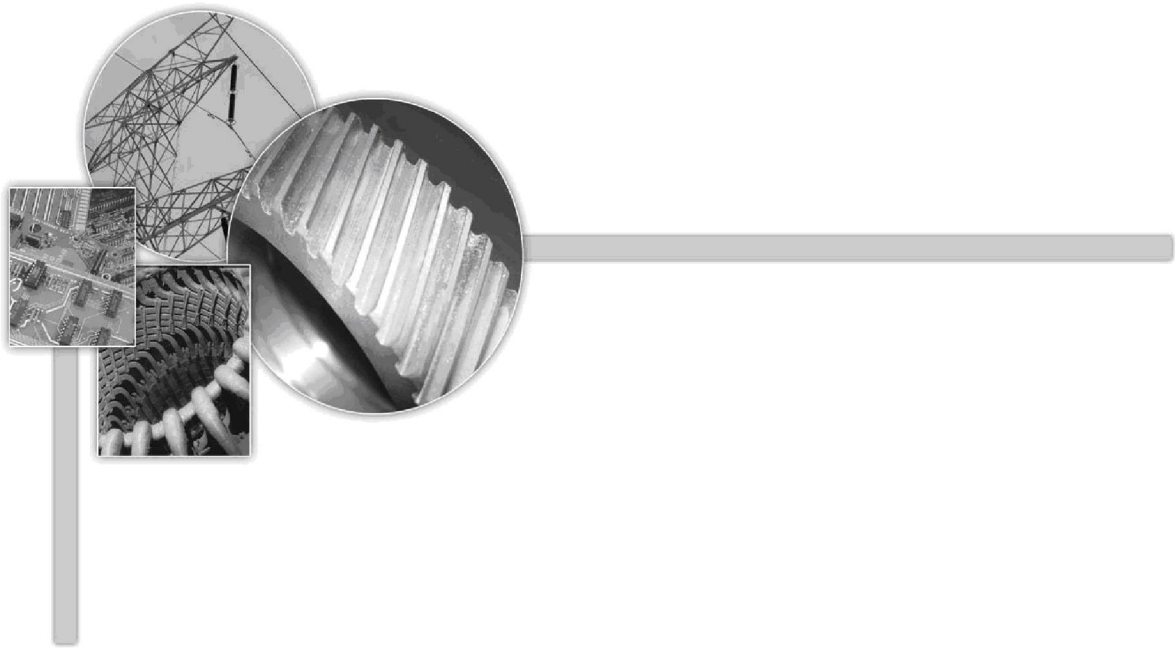


Fig. 1.3-12 DC Schematic for Local Back-Up Protection on Breaker Failure
(Single-Line Single-Breaker Bus)

12. List two disadvantages of One Timer Per Bus protection method:

- _____
- _____



UNIT 2

RELAY TESTING &.COMMISSIONING

UNIT-2

RELAY TESTING & COMMISSIONING

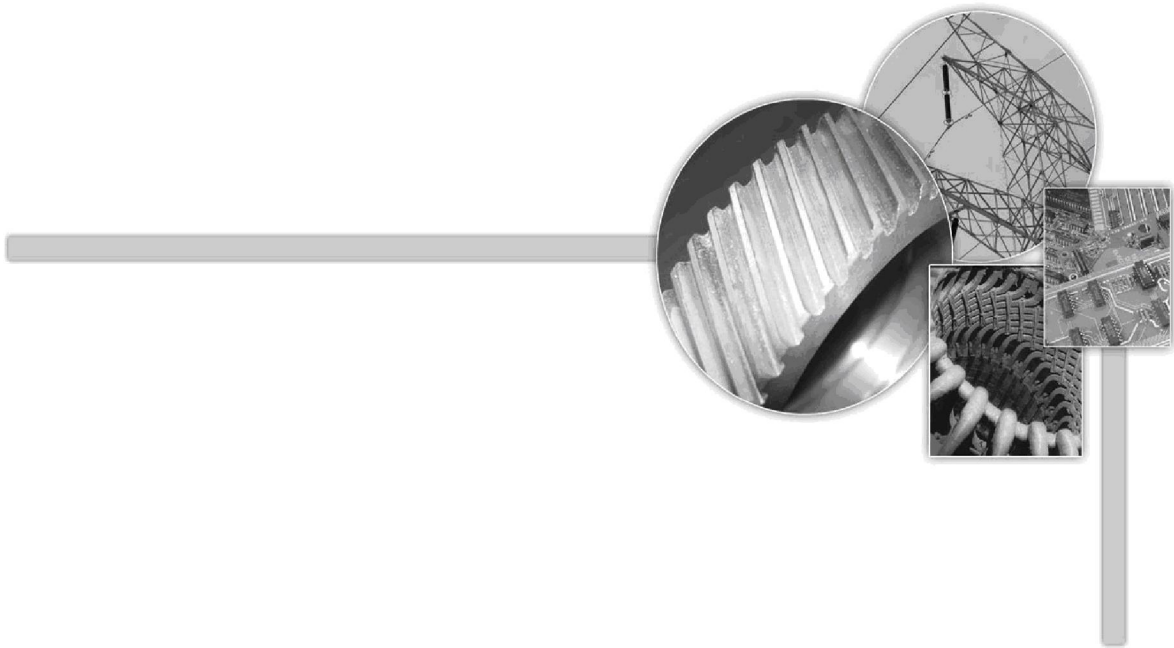
OVERVIEW

This unit discusses the different types of electrical diagrams and their using situations. The unit scopes out the tests and commissioning of protective relays. The unit also discusses the functional, in-service tests, and primary injection tests for protective relays.

OBJECTIVES

Upon completion of this unit, the trainee will be able to:

- List the different types of electrical diagrams.
- State the functional tests of the protective relays.
- Explain primary and secondary injection tests for protective relays.
- Define the energization and in-service tests of protective relays.



LESSON 2.1

ELECTRICAL DIAGRAMS FOR CONTROL DEVICES

LESSON 2.1

ELECTRICAL DIAGRAMS CONTROL FOR DEVICES

OVERVIEW

This lesson discusses the different types of electrical diagrams, such as block diagrams, single line diagrams, three line diagrams, elementary (schematic) diagrams, and wiring (connection) diagrams.

The lesson focus on different examples with attached drawing related to the electrical diagrams.

OBJECTIVES

Upon completion of this lesson, the trainee will be able to:

- Identify the block diagrams.
- Identify the single line diagrams.
- Identify the three line diagrams.
- Identify elementary (schematic) diagrams.
- Identify wiring (connection) diagrams.

INTRODUCTION

It would not be practical for industry to manufacture a product, raise a building, or assemble a transformer without using drawings, which provide the complete details for each of their tasks. A pictorial drawing shows a likeness of an object as viewed by the eye. In most instances, the detail drawings provide information on a single part, although all of a small and simple project might be shown on one drawing.

Electrical or electronic diagrams are drawings in which lines, symbols; letters and numbers combinations are used to represent electrical circuits. Electrical diagrams may also be called prints. Electrical diagrams are valuable tools for troubleshooting, commissioning, modifying, or erecting electrical equipment in a system. All electrical power systems should have available the up-to-date diagrams which truly represent the installed system.

Note:

It is hazardous to personal and equipment to try to operate or maintain a system without correct electrical diagrams.

There are different types of electrical diagrams. Each type is drawn differently to provide different information. These types of diagrams are classified as follows:

- Block Diagrams.
- Single Line Diagrams.
- Three Line Diagrams
- Schematic or “Elementary” Diagrams
- Wiring Diagrams
- Inter- Connection Diagrams

DIAGRAM CONVENTION

When studying an electrical diagram to determine how the system operates, you have to keep in mind the following:

- Electrical diagram shows the electrical devices in their de-energized state.
- Electrical diagram shows the mechanical operating devices in their de-energized state.
- Electrical diagram shows the electrical devices auxiliary contacts in the position as when their devices are in the de-energized state.

- Electrical diagram shows **DC** or **AC** supply in the off position.
- Electrical diagram shows air pressure or liquid level at their low levels.

BLOCK DIAGRAMS

A block diagram is a diagram that uses boxes, or blocks, to represent the major components in an electrical system. A block diagrams purpose is to provide a basic overview of a system and to show how the parts of the system are connected to each other. Block diagrams are usually rather simple. They do not have much detail and they do not include much information. A typical block diagram is shown in Fig. 2.1-1.

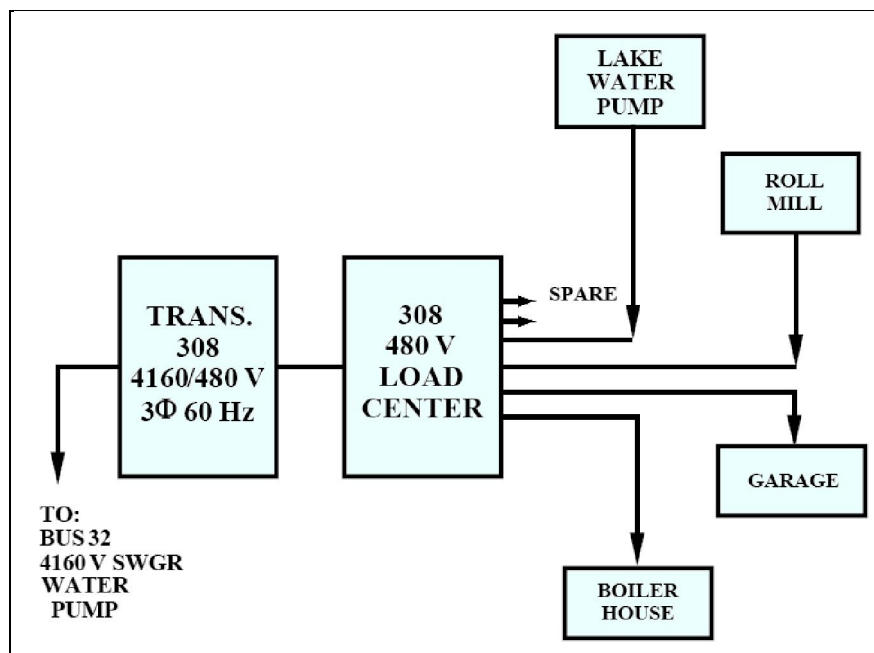


Fig. 2.1-1 Block Diagram

Technicians use block diagrams to see what parts are included in a system and what electrical order the parts are in. For example, the system shown in Fig. 2.1-1.

If the lake water pump does not operate for example, electrician can examine this block diagram and see that the lake water pump and its associated power equipment get their power supply from a **480 V** load center, number **308**. Therefore, if there is no power available to the pump and its associated equipment, then, according to the block diagram, the load center is the logical place to start looking for the cause of the

problem. While block diagrams can be useful to electrician in some ways, block diagrams do not do several things. For example, block diagrams do not accurately show the physical location of the components in a system. However, in some block diagrams, the physical locations of components are printed in or near the blocks. In addition, block diagrams use single line to represent electrical connections, but there is usually no indication whether the single line represents one cable or several cables.

SINGLE LINE DIAGRAMS

Single line diagrams are diagrams that show circuits as single lines. Their purpose is to give an overview of an electrical system. Single line diagrams typically use standard electrical symbols to represent the components in a circuit or system. They give more detailed information than a block diagram, and they may identify the general plant location of components.

The single line or one line diagram is the most basic diagram used in electrical power industry, because it actually a “short hand” method of expression that has remarkable flexibility. The single line diagram may be used in a very general and abbreviated manner to illustrate broad system ideas, or in a very detailed manner to illustrate all of the components in a particular part of the system. The single line does not represent actual wiring; it only indicates that some kind of connection exists between components. Typically, single line diagrams are used to show how power is distributed to various loads in a facility. This information is useful when determining how to isolate a part of the system for maintenance. Single line diagrams also can also be used to show how meters or protective devices are connected to the system. Along with identifying the components in a system, single line diagrams usually include additional information, such as:

- Rating of the major components.
- Voltage levels at various points in the circuit.
- Control functions provided in the circuit. For example, protective relays function in this circuit.

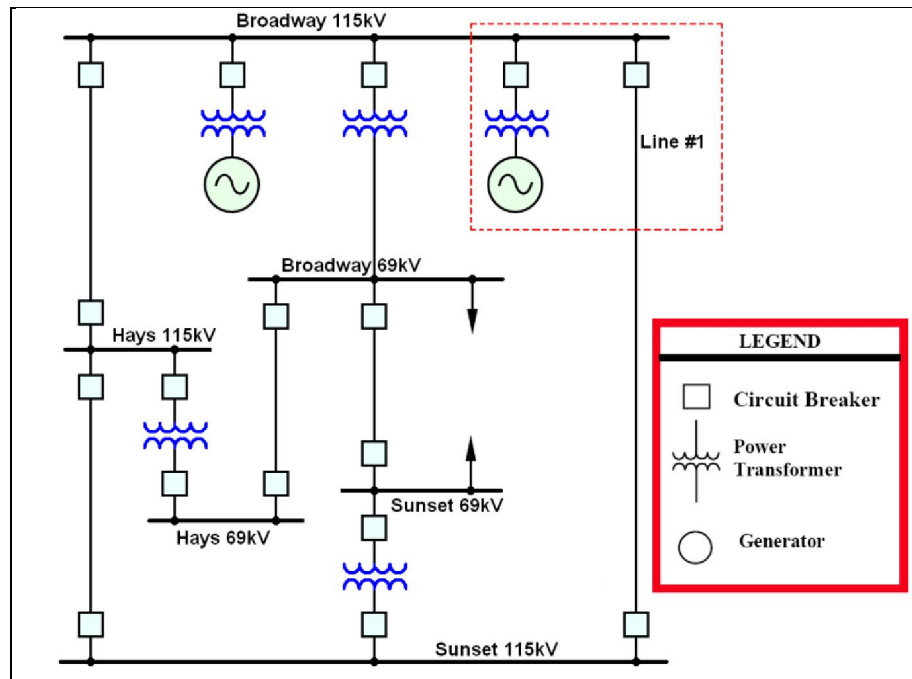


Fig. 2.1-2 General One Line Diagram Showing Part of Electric Utility

A single line drawing of an electrical system is often too large to fit on one page. When this occurs, arrows are used to indicate the drawing is continued on one or more pages. Fig. 2.1-2 shows one line diagram that is intended to highlight the power system itself with minimum emphasis on electrical equipment comprising in SEC network.

READING SINGLE LINE DIAGRAMS

In a single line drawing, the components are arranged in the order of decreasing voltage level. The highest voltage component is usually shown at the top or left of the drawing. To read a single line diagram, simply trace the flow of the power through the system if you want to identify all the components that are supplied with power in the panel, start reading at the highest voltage component and trace the path of the power through the entire drawing.

If you want to determine how power is supplied to a specific component, start at the component and trace the flow of power backwards through the drawing. This method could be used to locate the correct circuit breaker to isolate a component for maintenance.

In general, single line diagrams are read by selecting a starting point (usually the point nearest the power supply) and following the single line through the entire diagram. The attachment drawings show a typical single line diagram for one of SEC areas. By tracing the last single line diagram, it shows the following information.

- a. General overview to highlight the main electrical equipment in the grid station.
- b. General overview to highlight to show how meters, or protective devices are connected to the system.

CONTENTS OF GRID STATION

The highest voltage 69 kV is supplied to the grid station and tied to the 69 kV network through 6 transmission lines connected to the 69 kV bus bar (**BB**). These lines are:

- **Line #1** coming from Sharq grid station and connected to **BB-1** through a draw-out type circuit breaker “**C₁**.”
- **Line #2** coming from Khobar BSP and connected to **BB-2** through a draw-out type circuit breaker “**C₃**.”
- **Line #3** coming from Khobar BSP and connected to **BB-3** through a draw-out type circuit breaker “**C₅**.”
- **Line #4** coming from Aziziah grid station and connected to **BB-4** through a draw-out type circuit breaker “**C₇**.”
- **Line #5** coming from Aziziah grid station and connected to **BB-4** through a draw-out type circuit breaker “**C₈**.”
- **Line #6** coming from Khobar BSP and connected to **BB-5** through a draw-out type circuit breaker “**C₁₀**”

The 69 KV **BB** is a sectionalized bus and it is divided into five sections by a sectionalizing disconnect switches {89S/12, 89S/23, 89S/34, and 89S/45}, these disconnect switches are manually operated. The five bus sections are:

- | | |
|------------------------|------------------------|
| • BB1 (Cell #1 & #2). | • BB 2 (Cell #3 & #4). |
| • BB3 (Cell #5 & #6). | • BB4 (Cell #7 & #8). |
| • BB5 (Cell #9 & #10). | |

There are four step-down transformers **TRAFO** type with a ratio of 66 kV/ 13.8kV. Each transformer is **25-30 MVA**, the phases are connected to form vector group **Dyn1** with a grounded neutral. The transferors are equipped with automatic on-load tap changer with an “**AVR**” The transformer high voltage and low voltage bushings are protected by surge absorbers. The four transformers are connected as follows:

TRANSFORMER #1

- a. High-tension side is connected to 69kV **BB-1** through oil circuit breaker **C₂**.
- b. Low-tension side is connected to 13.8kV **BB-(a₁)** through oil circuit breaker **T₁**.

TRANSFORMER #2

- a. High tension side is connected to 66kV **BB-1** through a draw-out type oil circuit breaker **C₄**
- b. Low-tension side is connected to 13.8kV **BB-(b₁)** through a draw-out type oil circuit breaker **T₂**.

TRANSFORMER #3

- a. High tension side is connected to 66kV **BB-1** through a draw-out type oil circuit breaker **C₆**
- b. Low-tension side is connected to 13.8kV **BB-(a₂)** through a draw-out type oil circuit breaker **T₃**.

TRANSFORMER #4

- a. High tension side is connected to 66kV **BB-1** through a draw-out type oil circuit breaker **C₉**
- b. Low-tension side is connected to 13.8kV **BB-(b₂)** through a draw-out type oil circuit breaker **T₄**.

There are two auxiliary transformers, they step-down voltage from 13.8kV to 0.380kV & 0.220kV. Each transformer rating is 400kVA, the primary phases are connected in Δ and the secondary phases are connected in Y with a grounded neutral. HV bushings are protected by surge absorbers. The two transformers are connected as follows:

AUXILIARY TRANSFORMER #1

- High tension side is connected to 13.8kV **BB-(a1)** through a draw-out type oil circuit breaker **A₁**
- Low tension side is connected to the Distribution Panels through the Automatic Transfer switch “ATS”

AUXILIARY TRANSFORMER #2

- High-tension side is connected to 13.8kV **BB-(a2)** through a draw-out type oil circuit breaker **A₂**.
- Low tension side is connected to the Distribution Panels through the Automatic Transfer switch “ATS”

There are eight 13.8 kV feeders on each connected to each 13.8 kV bus bar through a draw-out type CB (F).

INSTRUMENT TRANSFORMERS

On each TL, there are three **PT**'s & three multi tap **CT**'s. Each **PT** ratio is $69/\sqrt{3} / 0.100/\sqrt{3} / 0.100/\sqrt{3}$ and they have 2- secondary, one used for measuring and the other one used for protection. Each **CT** ratio is $(400 - 800) / 5$ and they have 3-secondaries, one for measuring, one for protection and the third one is spare. See Fig. 2.1-3.

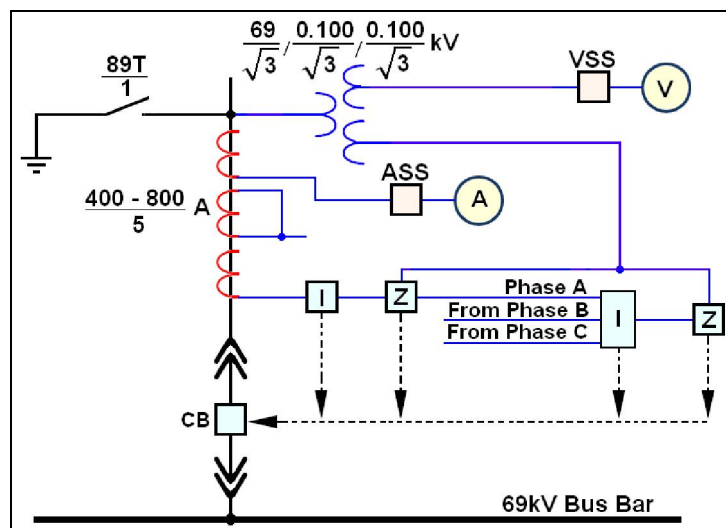


Fig. 2.1-3 69kV Feeder with its Measuring and Protection

On the primary side of the transformer, there are three CT's, each CT has one secondary, and it uses for protection. See Fig. 2.1-4. On the secondary side there are two sets of a three CT's; one set is located before the CB (T), and each CT has two secondary, one for measuring, & other for protection. The other set of CT's is located after the CB (T), and each CT has one secondary, which uses for protection.

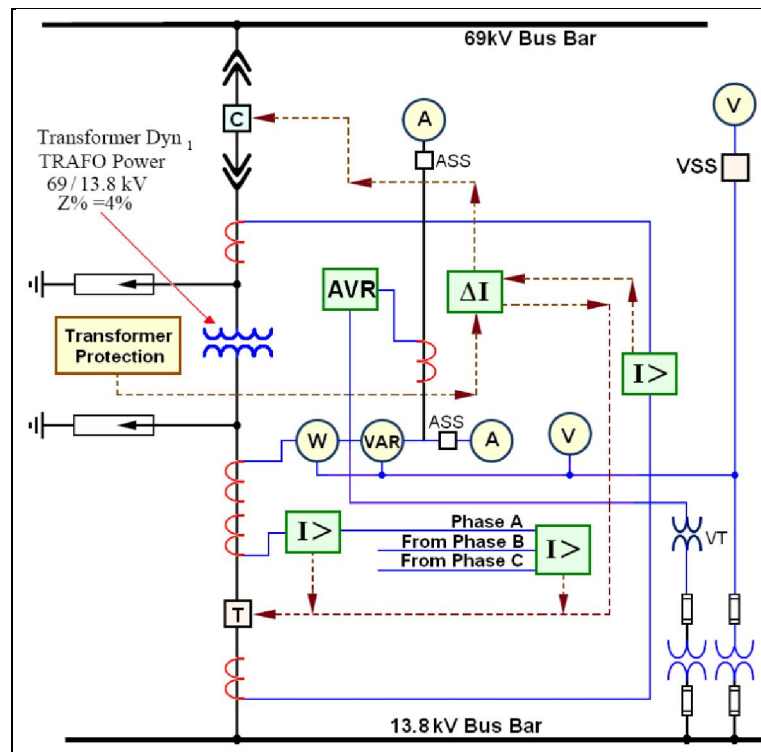


Fig. 2.1-4

On the 69 kV BB2 there are three **PT**'s, each phase has two secondary used for measuring and synchronizing. See Fig. 2.1-5.

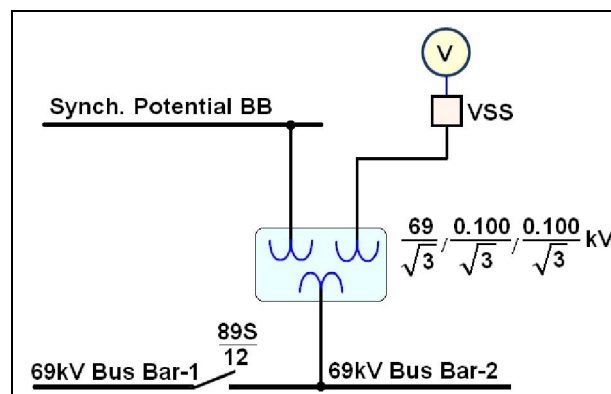


Fig. 2.1-5

On each 13.8 kV auxiliary transformer there is three phase **CT**'s located after the CB (F), each phase has two secondary one is used for measuring and the other used for protection.

METERS & PROTECTIVE DEVICES

TRANSMISSION LINE PROTECTION

The transmission line is protected by three phase distance relay, ground distance relay, three phase overcurrent relays and ground overcurrent relay. All relays trip the line CB.

TRANSMISSION LINE METERING

There is single phase ammeter “A” & ammeter selector switch “ASS” to measure the three phase currents and a single phase voltmeter “V” & voltmeter selector switch “V_{ss}” to measure the three phase voltage.

TRANSFORMER PROTECTION

The transformer is protected by three phase differential relays, transformer protective devices (such as, Buchholz relay, winding & oil temperature switches, pressure relay, etc.), three phase overcurrent relays and ground overcurrent relay. The differential relays and the transformer protective device trip both circuit breakers on the high & low voltage side. The phase overcurrent relay and ground overcurrent relay trips the low voltage side **CB** only.

TRANSFORMER METERING

1. The 69 kV control panel has a single-phase ammeter “A” & ammeter selector switch “ASS” to measure the three phase currents and a single-phase voltmeter “V” & voltmeter selector switch “V_{ss}” to measure the three phase voltages.

2. In the 13.8 kV control panel there is a three, single-phase ammeters “A” to measure the three phase currents. Three, single-phase voltmeter “V” are used to measure the three phase voltages. Also, three-phase wattmeter “W” and three-Phase “VAR” meter.

FEEDER PROTECTION

The feeder is protected by a three-phase overcurrent relays and ground overcurrent relay. All relays trip feeder CB “F”. See Fig. 2.1-7.

FEEDER METERING

There is single-phase ammeter “A” & ammeter selector switch “ASS” to measure the three phase currents. See Fig. 2.1-7.

AUXILIARY TRANSFORMER PROTECTION

The auxiliary transformer is protected by three-phase overcurrent relays and ground overcurrent relay. All relays trip feeder CB “F”. See Fig. 2.1-7.

AUXILIARY TRANSFORMER METERING

There is single-phase ammeter “A” & ammeter selector switch “ASS” to measure the three phase currents. See Fig. 2.1-7.

THREE LINE DIAGRAMS

Three line diagrams serve exactly the same functions as single line diagrams except they give more information for each component such as:

- Number of devices per circuit.
- Connection details.

Fig. 2.1-8 shows the three-line diagram for the transmission line shown in Fig. 2.1-3.

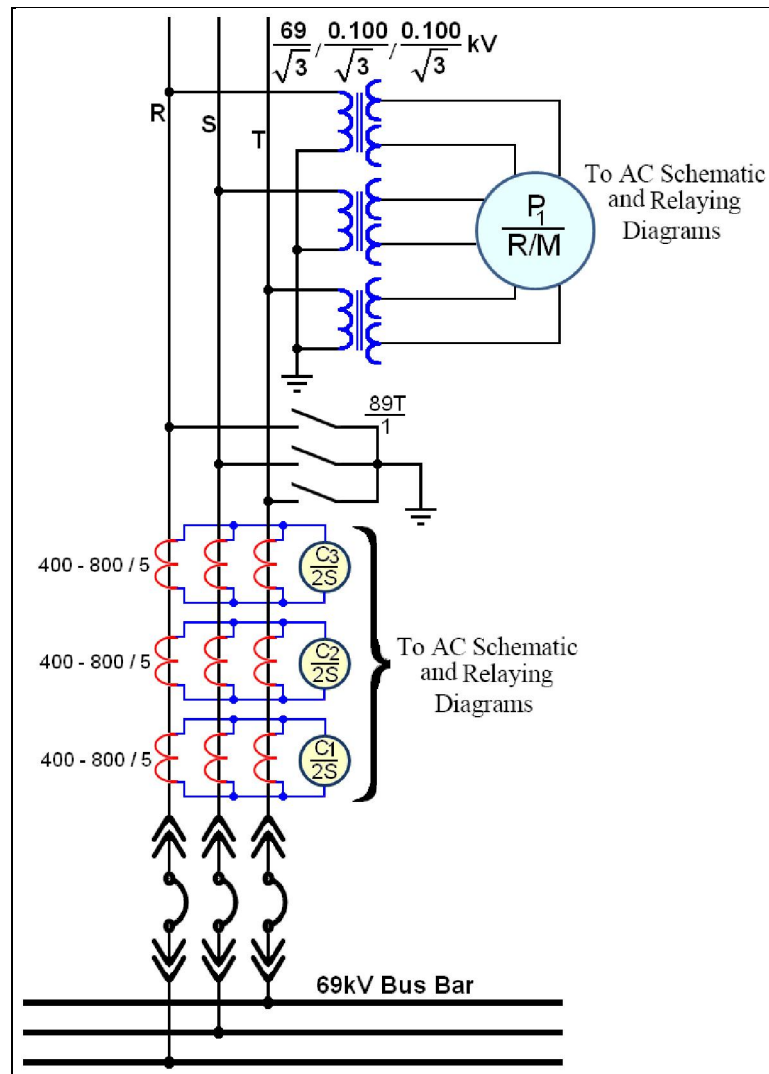


Fig. 2.1-8 Three-Line Diagram

ELEMENTARY (SCHEMATIC) DIAGRAMS

While single line diagram is useful for a power distribution system, a representation of control system is made with an elementary diagram (schematic diagram).

Schematic diagrams are diagrams that show all components in a unit and how they are electrically connected. Schematic shows component in their proper electrical positions, but not necessarily in their proper physical positions. Therefore, a schematic can be used to find out how the circuit is designed to operate. The position of the contacts and switches, as they would be in the relaxed, and de-energized, state. Schematics usually include sequence of operation, and switch description chart. See Fig. 2.1-9.

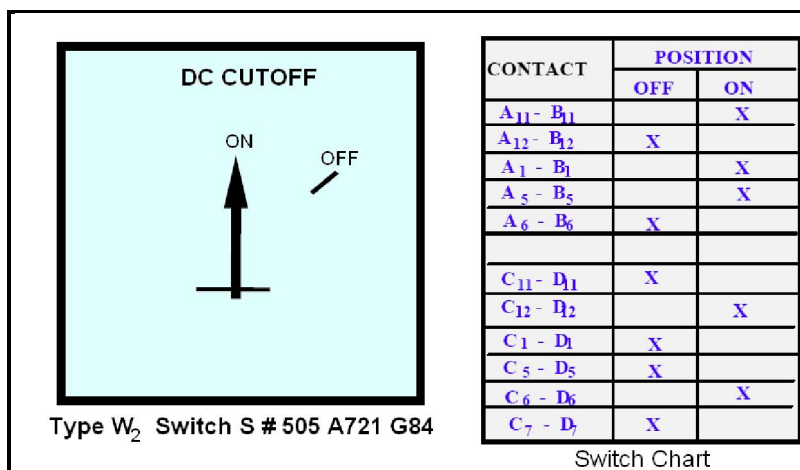


Fig. 2.1-9 Elementary (Schematic) Diagram

Switch chart includes information such as:

- Switch function.
- Switch set points.
- Operation of multiple-contact switches.

Schematics typically use standard electrical diagram symbols and device function numbers. In schematics when a circuit has more than one coil operated device, the device that is operated first would be located above the other one; this makes it easier to follow the sequence of operation. Generally, schematic shows the circuit in the de-energized condition.

In schematic diagrams, a single device may be visual as being broken into several pieces. This breaking-up of components serves to understand the logic control. In addition, the main power circuits are shown separate from control components. Schematics are very important tool for the technicians and they use them to:

- Determine the sequence of operation in a circuit.
- Troubleshoot the control circuits.
- Modify the circuits.
- Perform Commissioning on the new circuits.

TYPES OF SCHEMATIC DIAGRAMS

- AC or relay in schematics. See Figures ((4-a), (4-b), (5-a). (5-b)) In the attachment drawings.
- DC schematics. See Figures (6, 14) in the attachment drawings.

READING OF SCHEMATIC DIAGRAMS

As mentioned before schematics are normally drawn to show the circuit in the de-energized condition. The power supply is located at the top left of the diagram. The load is located at the bottom right of the diagram. Schematics are usually designed to be read from left to right and from top to bottom.

To understand how a circuit is designed to operate, you have to visualize what happens when the circuit is energized, and you must first identify the component within the circuit. Once the components have been identified, trace the flow of current through the schematic to do this:

- Start at one end of the schematic. (Either the component or the power supply.)
- Trace through the circuit to see what must happen for the component to become energized.
- Imagine that the circuit is energized.
- Follow the same procedure to see how the circuit is returned to the de-energized condition.

INSTRUCTIONS FOR READING SCHEMATICS OF CB CONTROL

The closing or tripping circuit for any circuit breaker almost has the same components. Some CB's have extra components according to the type of their tripping mechanism. The technician can get the necessary information about these devices from the instructional manual for that particular circuit breaker. When reading the DC schematics for circuit a breaker the technician has to identify the component within the circuit. Once the components have been identified, trace the flow of current through the schematic.

CLOSING CIRCUIT OF CB

In the schematics for CB closing circuit, the technician can identify the following main components in the circuit:

- DC supply.
 - Closing coil.
 - Normally closed contact of the circuit breaker auxiliary switch (52-b).
 - Contact to indicate that the circuit breaker has enough force for closing otherwise it will block the CB operation. This force could be as result of:
 1. Stored energy in a closing spring [a limit switch (LS) will be used to indicate if the closing spring is charged or not],
 2. Pressurized air, [a pressure switch (63) will be used to indicate if the air has enough pressure or not].
- Mode selector switch.
 - Anti-pumping relay
- Main control switch

TRIPPING CIRCUIT OF CB

In the schematics for CB tripping circuit, the technician can identify the following main components in the circuit:

- DC supply.
- Main control switch
- Normally open contact of the circuit breaker auxiliary switch (52-a).
- Tripping coil.
- Mode selector switch.

WIRING (CONNECTION) DIAGRAMS

Wiring diagram shows exactly how the wires in a circuit are connected. A circuit could be wired in various ways for it to operate as the schematic indicates. So the wiring diagram is important because it tells the technician how the circuit is actually wired

The wiring diagram shows the relative location of all components, wires, and terminal (connection) points, in the circuit that it represents. This information is useful when attempting to locate a particular component or wire in a panel.

Wiring diagrams are very important tool for the technicians and they use them to:

- Troubleshoot the control circuits.
- Modify the circuits.
- Perform Commissioning on the new circuits.
- Locate a particular component or wire in a panel

With simple equipment, all connection can be shown on a single sheet of drawing and could be installed in one panel. In complex systems, more than single sheet of drawings could be used and more than one panel in a different location could be used

CHARACTERISTICS OF WIRING (CONNECTION) DIAGRAMS

Like a schematic, a wiring diagram usually shows the circuit in the de-energized condition. A wiring diagram is drawn to show the circuit from a particular view. This view labeled on the diagram. Various views that used include:

- Front view.
- Rear view.
- Top view.
- Side view.

When looking at a circuit panel from the same view labeled on the wiring diagram, you will see the circuit component in the same relative location as they are shown in the diagram. Wiring diagram generally use:

- Graphic symbols and device designations to represent components.
- The same numbers to identify wires as used in the schematic.
- Solid lines to represent wires in a panel.

Dashed lines to represent wires running between panels, or to a remote location outside of a panel.

USING WIRING DIAGRAMS FOR CIRCUIT MODIFICATION

A schematic and a wiring diagram are used together for most electrical jobs. The schematic shows how the circuit is designed to operate. The wiring diagram shows how the components are wired together and where they are located in relation to one another. Therefore, when a circuit is modified, a schematic is used to determine in what part of the component must be placed to perform its function. When that has been determined, a wiring diagram is used to determine where the connection can actually be made. Usually, there are several connection, or terminal, points available. In transformer protection circuit shown in Fig. 2.1-10, the main protections of the transformer are differential relays “87” and Buchholz relay “63.” The Buchholz relay

is used to give an alarm only and the differential relays are assigned to trip the transformer circuit breakers through the lockout relay “86.”

The relay engineer modified the scheme by Buchholz relay to isolate the transformer in case of a major internal fault.

From the schematic diagram, we can determine that the Buchholz relay is added to isolate the transformer through the lockout relay”86”. In the wiring diagram, The Buchholz relay could be connected to “86” terminal directly or through the terminal block “TB”.

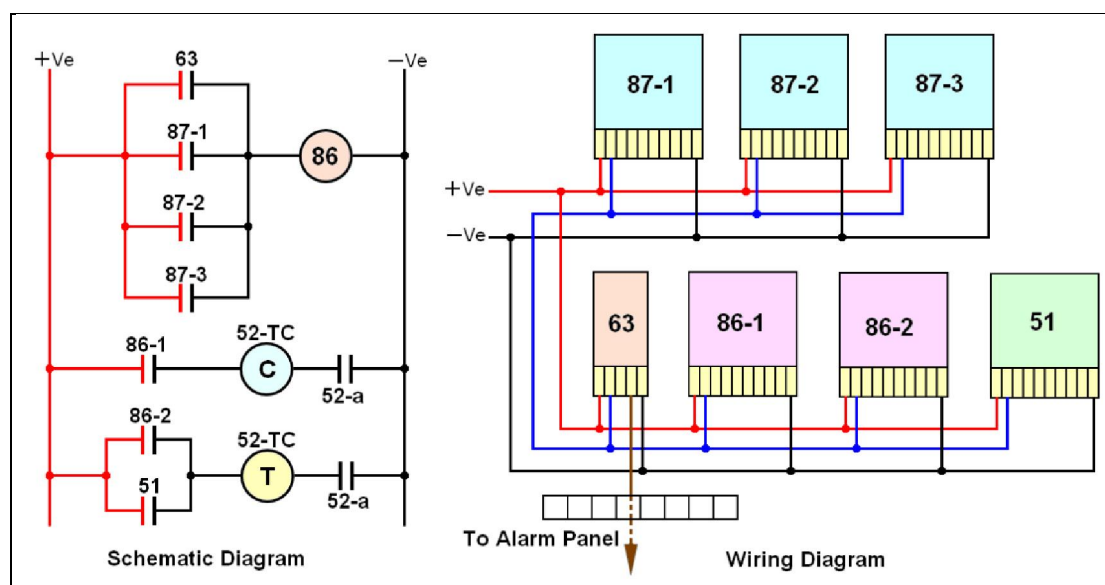


Fig. 2.1-10 Schematic and Wiring Diagram

APPLICATIONS ON READING SCHEMATICS

Tracing the 69 kV Transmission Line Protection and Control in the attachment drawings.

AC SCHEMATICS

In the AC schematic, there are two instrument transformers showing Potential transformer, (P_1 / R/M), which is connected to the line. Each phase has a single **PT** with two secondary windings one for measuring and the other for protection. This transformer is connected star and its ratio is $\{69/\sqrt{3} / 100/\sqrt{3}/100/\sqrt{3}\}$ volt.

Each secondary winding is connected with its respective load through non-fuse switches. The first secondary winding of the PT is connected through non fuse switch NHSC #1 to the voltage coils in the distance relays $21Z_1$, $21Z_2$, $21Z_3$ and into the ground distance relay $21GZ_1$, $21GZ_2$, $21GZ_3$ as shown in Figure (4-b). The other secondary windings of the PT are connected through non-fuse switch NHSC #2 to the voltmeter selector switch then to the line-1 voltmeter as shown in Figure (4-1-a).

These two non fuse switches NHSC # 1 & NHSC # 2 have two auxiliary contacts; one is normally close (3-7) and the other one is normally open (1-2). When NHSC # 1 is closed it will supply the protective relays with the AC voltage through the main contacts, and supply it with DC supply through its normally open auxiliary contact (1-2). But when NHSC #1 trips, it will give an alarm (Distance Relay Potential & control supply failure through the normally closed auxiliary contact (3-7). Similarly, when NHSC # 2 is closed, it will supply the measuring instruments with the AC voltages through the main contacts. Also, when NRSC # 2 trips it will give an alarm (Distance Relay Potential & Control supply failure) through its normally closed contact (3 -7).

Current transferors $C_1/1S$ & $C_1/3S$ are connected star connections $C_1/1S$ is connected to the line ammeter through ammeter selector switch as shown in Figure 4.a. and the other CT. $C_1/3S$ is connected to the current coil in the distance relays $21Z_1$, $21Z_2$, $21Z_3$, ground distance relays $21GZ_1$, $21GZ_2$, $21GZ_3$ and instantaneous overcurrent relay 50 and ground overcurrent relay 50G as shown in Figure (4-1-b).

DC SCHEMATICS

PROTECTIVE RELAY CONTROL CIRCUIT (Distance Relay Control)

In the circuit shown in Figure (5), we have:

$21Z_1, 21Z_2 \text{ \& } 21Z_3$	Phase distance relays for zone-1,2&3
$21GZ_1, 21GZ_2 \text{ \& } 21GZ_3$	Ground distance relays for zone-1,2&3
50 & 50G	Ins. Overcurrent & Earth Fault relays (Act as non-Directional over current step i.e. zone-4.
74 / DC	Control supply failure relay

94	Breaker trip auxiliary relay
94 X	Distance relay trip alarm auxiliary relay
94 Y	Auxiliary. Relay (operate with 94 only at starting)
21 X	Zone 2 & 3 timers
21 Y	Zone 4 timer
62 L	Zone-1 timer
94 TT	Transfer trip timer
85 (BD x 12 – 0)	Pilot wire signal device
43S /Z ₁	Relay mode selector switch
74	Alarm relay
Fu	Fuse
68X	Power swing auxiliary relay
Ps	Power supply auxiliary relay

CONTROL DC SUPPLY SUPERVISION

This is done by the auxiliary relay 74/DC, which is normally energized. When there is any supply, failure 74/DC will make reset and give alarm. (Distance Relay Potential and Control Supply Failure).

PHASE & GROUND DISTANCE RELAY OPERATION

Zone-1 phase-distance 21Z₁

When there is a fault in zone-1, 21Z₁, operate and close its contact, we have +ve at terminal 21Z₁/12, then pass through 68x (3-4) to 43S-(3-3c) that depends upon the selected mode of operation, i.e. with or without transfer trip (94TT).

WITHOUT TRANSFER TRIP

When we select the mode of operation to be instantaneous and without transfer trip, i.e. mode selector switch 43S/Z₁ (3-3C) should be closed and mode selector switch 43S/Z₁ (6-6C) and 43S/Z₁ (4-4C) should be open. When there is a fault in zone-1, 21Z₁

closes its contact and energize the auxiliary relays 94, 94X and 94Y. 94 will trip the CB, 94 X will initiate an alarm (Distance Relay Start), 94Y will open its two normally close contacts, and the 94 will be held close through resistor (RES) until the breaker trips.

WITH TRANSFER TRIP

When we select the mode of zone-1 operation to be with a transfer trip, i.e. mode selector switch 43S/Z₁ (3-3C) open and mode selector switch 43S/PO (4-4C) and 43S/PO (6-6C) should be closed. When there is a fault in zone-1, 21z₁ closes its contact, energizes the auxiliary time delay relays (62-1) /TDPU & TU1-94TT, and energizes the pilot wire signal device. When (62-1)/TDPU closes its contact it will energize the auxiliary relays 94, 94X, and 94Y. When 94TT close its contacts, the trip is transferred to the other side.

WITHOUT TIME DELAY

43S/Z₁ (3-3C) closes and 43S/PO (6-6C) opens, then the +ve Pulse will pass through the two normally closed contacts of 94Y to energize the auxiliary relays 94 & 94x. Auxiliary relay 94 will trip the breaker and auxiliary relay 94x will initiate an alarm (Distance Relay Start). When 94Y NC-contacts opens, it will leave the +ve on 94 through the resistance until the breaker is tripped.

WITH TIME DELAY

43S/Z₁ (3-3C) opened and 43S/PO (6-6C) closed. In this case the +ve after 68X (3-4) will pass to energize the zone-1 timer (62L/TDPU), after its time setting it will energize the auxiliary relays 94, 94X, and 94Y. When 94TT close its contacts, the trip is transferred to the other side. The transfer trip will be for zone-1 only and if there is a fault in the 3rd zone 21z₃ will close its contact and send a signal to 85P to block the operation of 94TT.

Zone-1 Phase Distance 21G Z1

When Zone-1 Ground Distance Relay 21GZ₁ energized, it will close its contact 21GZ₁ and it will do the same function of zone 1 Distance relay 21Z₁.

Zone 2 Phase Distance Relay 21Z₂ & Ground Distance Relay 21GZ₂

When 21Z₂ or 21GZ₂ operates or both at the same time. They will energize the timer 21X (TU₁) to close its contact after its time setting, then +ve will pass from 21X/1 to 21X/2 and diodes (4 – 6) to the trip the line as zone-1. Also, it will send a signal to energize bus X5, which will energize the auxiliary relay 74 to give an alarm (Distance Relay Start).

Zone 3-Phase Distance Relay 21Z₃ Ground Distance Relay 21GZ₃

When 21Z₃ or 21GZ₃ energize the timer 21X (TU₂) to give a trip signal. Also, it will energize bus-5 which, will energize the auxiliary relay 74 to give an alarm

Power Swing Aux. Relay 68X

When zone-2 distance relay closes its contact (7-8), the (+)ve signal will pass to energize 68X through its normally closed contact (7-8), which will be opened and 68 X will continue energized through the resistance R₂/200. When 68 X is energized its contacts (3- 4) and (5-6) will open and block the trip order from the zone-1 distance relay during power swing.

Zone-4 Protection “Overcurrent (50) & the Earth Fault (50 G)”

Zone-4 is a backup protection, operation of 50 or 50G relays will energize the timer 21Y (TU), to energize the common trip bus through bus # 3 and diode (4-6).

Pilot Cable Supervision

When there is any failure in the pilot cable which carry the transfer trip orders, relay 85/P183 (BDX) will close its contact (25-26), that will energize PWD through 94-X contact to initiate an alarm (Failure in Pilot Cable).

CIRCUIT BREAKER CONTROL CIRCUITS

Circuit Breaker Closing (Figure (6))

43 LR	Local Remote Changeover Switch
52CS/C	Circuit Breaker Control Switch for Closing
42I	Carriage Motor Contactor For Plug In Position
42E	Carriage Motor Contactor For Draw-out Position
63X1 & 63 X2	Auxiliary Relays of Pressure Switch
52 _{z1} & 52 _{z2}	Interlock Relays (Prevent Closing With Persistent Opening Signal
52/Y 1, 2, 3	Anti-Pump Relay (Poles 1, 2, 3)
33	Carriage Motor Interlock Switch
52/ 1, 2, 3	Circuit Breaker Auxiliary Contacts
52/ EC 1, 2, 3	Closing Electro-Valves (poles 1, 2, 3)
N	Breaker Operation Counter
52 MCC/L	Close Local Control Switch

Legend to Figure (6) in the Attachment Documents

The circuit breaker can be closed from three locations:

1. Locally from the **CB** control panel.
2. Remote from the **SS** control room.
3. Remote from the power dispatcher through **SCADA** System.

CLOSING CB FROM BREAKER CONTROL PANEL

To close the CB locally the following condition should be satisfied:

1. The magnetic contactors “**42I & 42E**” to Rack In/Out the **CB** carriage should be de-energized i.e. their **NC** auxiliary contacts “**42I & 42E**” should be closed.
2. There is no trip-signal, either for the main trip circuit (Auxiliary contact 1-2 for 52z1) should be closed, or for the auxiliary trip circuit (Auxiliary contact 1-2 or 52z2) should be closed.

3. The anti pumping Relay 52Y1, 52Y2, and 52Y3 should be de-energized; i.e. their contacts 1-2 should be closed.
4. The CB should be in the IN-position or in the Test-position i.e. carriage motor interlock limit switch 33 NC contact should be closed.
5. The CB should be in the off position i.e. its auxiliary switch TC contacts (7-8) 52-2 and 52-3 should be closed.
6. The DC control power should be available. Then to close the CB we have to follow the following:
7. Put the mode selector switch 43-L in the local position i.e. its contact 1-3 should be closed.
8. Put the local control switch (52-MCC)/L in the ON position i.e. its contact (5-8) should be closed and when you release the control switch (52-MCC)/L it will return back to the normal position by the spring action. When (52-MCC)/L close its contact (5-8) then the CB closing coils 52EC-1, 52EC-2, and 52EC-3 should energize and close the CB. When the closing operation is completed the auxiliary contact of the breaker change its position i.e. the contacts {52/1, 52/2, 52/3} (7-8) opens and {52/1, 52/2, 52/3} (5-6) closed, that is to say that {52/Y₁, 52/Y₂, 52/Y₃} is energized and self hold through (52-MCC)/L contact 5-8, 43/L (1-3) and its contacts {52/Y₁, 52/Y₂, 52/Y₃} (5-6) and {52/Y₁, 52/Y₂, 52/Y₃} (1-2) open and opens the +ve pass of closing order, i.e. it prevents pumping, N also is energized and count the closing operations.

Closing, the CB Remote from the Control Room

All the condition for closing the CB locally should be satisfied. The following steps should be done to close the CB remote from the control room:

1. Put mode selector switch(43-R) in the Remote position i.e. its contact 43/R (2 -4) should be closed
2. Switch the mode selector switch (43/LR) in the control room to local position, i.e. its contact (1-2c-1) should be closed.

3. Switch the control switch 52CS/C to the close position i.e. its contact (1-1c) should be closed; when 52CS/C is released, it will return back to the neutral position by the spring action.

Closing the Circuit Breaker Remote from the Power Dispatcher

Closing **CB** remote from power dispatcher is similar operation as closing from control room except closing signal is done through **(43-LR)/R** and the supervisory contact.

CIRCUIT BREAKER OPERATION

99CS	Breaker Switch Position
94	Breaker Trip Auxiliary Relay
75-I	Carriage Limit Contacts
52/EA ₁ , 52/EA ₂ , 52/EA ₃	Opening Electro-Valves (Poles 1, 2& 3)
GL	Green Lamp
RL	Red Lamp
63-AI	Air pressure switch: causes the breaker opening and prevents breaker closing on low pressure
63-GL	Gas pressure switch: do the same as 63A
(52-CS)/trip	Circuit breaker control for tripping
52-MCA	Opening Local Control Switch
(89-T)/C	Auxiliary Contacts for Earth Switch
99	Semaphore indicator

The Main Opening Circuit For The Circuit Breaker (figure (7) in the attachment)

Circuit breakers can be opened either manually or automatically by means of protective relays.

Opening Circuit Breaker by Manual Operation

To open a CB manually the following conditions should be satisfied:

1. CB should be closed i.e. its auxiliary switch normally opened contacts 52/1, 52/2, 52/3 (a-10) should be closed and normally closed. Contacts 52/1, 52/2, 52/3 (23-24) should be opened.
2. The gas (Air) pressure required for circuit breaker operation should be enough, i.e. pressure switch **63-GI** should be de-energized.
3. The D.C. control power should be available.

CB can be opened manually either: -

- a. Locally from **CB** Local Control Panel.
- b. Remote from Control Room.
- c. Remote from Power Dispatcher.

TABLE P.- Local operation from circuit breaker local control panel

To open the **CB** from its local control panel you have to do the following steps:

1. Put the mode selector switch 43 in the local position its N.C. contact 7-5 should be closed.
2. Then put the control switch (52-MCC)/L to the trip position.

Table P.- Remote Operation from Control Room

1. Put the mode selector 43 in CB control panel to the Remote position i.e. its contact **43/R (8-6)** should be closed.
2. In the control Room select local operation by putting the mode selector switch (43LR)/L to the local position i.e. its contact **43LR (34C-3)** should be closed.
3. Put the control switch **52CS** to the trip position i.e. its contact (**3-2**) will be closed.

Table P.- Automatic Opening Operation for Circuit Breaker

When one or more protective relays operates it energize the auxiliary relay 94 which closes its contact (1-7), to allow the +ve to pass through 75-I contact 3-4 (this is closed when the breaker carriage is in the correct position either in the Service position or in the Test position) then through' 63-X₁ contact 3-4 (which is closed when air pressure is enough) to energize the trip bus, then the operation continue as explained in manual operation.

Table P.- Remote Operation Power Dispatch Center

The same as remote opening from control room, but through (43LR)/L & supervisory contact. Then the +ve will pass through 63-X₁ & 63-X₂ contacts (which are closed when the air pressure is high enough). After this the +ve passes through 32-z₂ (which is closed when there is no opening signal existed at this moment). The +ve passes through (52/Y₁, 52/Y₂, 52/Y₃) (anti-pump relay normally closed contacts, and then go through 33 contact to the trip bus.

REVIEW EXERCISE

SECTION A

READ THE FOLLOWING STATEMENTS THEN SELECT TRUE OR FALSE

		T		F
1	Schematic shows all the components in a unit in their proper physical and electrical positions.			
2	It is necessary to know how a circuit is designed to operate before troubleshooting the circuit.			
3	The title block is located in the lower right corner of the diagram.			
4	Title blocks contain information that identifies an electrical diagram.			
5	The legend on an electric diagram identifies all types of electrical drawings.			
6	Interconnection diagrams are a natural extension of wiring diagrams that show external and internal connections between unit assemblies or equipment.			
7	Wiring diagram usually shows the circuit in the energized condition.			
8	Schematics are usually designed to be read from left to right and from top to bottom.			
9	The wiring diagram shows how the circuit is designated to operate.			
10	Wiring diagram generally does not use the same numbers to identify wires as used in the schematics.			
11	Switch chart includes information such as, switch size.			
12	In a single line drawing the components are usually arranged in the order of decreasing voltage level.			
13	Single line diagram is a valuable tool for troubleshooting, an electrical equipment in a system.			
14	It is hazardous to personnel and equipment to try to operate or maintain a system without correct electrical diagrams...			
15	The notes on an electrical diagram usually give detailed information about the latest revision to the diagram.			

SECTION B

1. What does one line diagram show?

2. What is the purpose of one line diagram?

3. What does schematic diagram show?

4. How much detail is included in a wiring diagram?

5. What is a block diagram?

6. **Fill in the space:**

- In order to locate component physically in a unit, the type of diagram to be used is a _____ diagram.
- A wiring diagram usually shows the circuit in the _____ condition.
- Schematic show component in their proper _____ positions, but not necessarily in their proper. _____ positions
- To read a single line diagram, simply _____ the flow of the power through the system.
- The _____ usually contains information that identifies the diagram.
- _____ identify symbols and designations that are used on electrical diagrams.
- Single line diagrams are used to show how power is _____ to various loads in a facility

SECTION C**Circle the Correct Answer**

- a. Which of the following is usually related to block diagrams actually shows the physical location of parts in a system.

- b. Indicate whether the single line running between the blocks represents one or several cables.
 - c. Show what electrical order the parts in the system are in.
 - d. None of the above.
-
- 1. Schematics are usually read from _____
 - a. Right to left and from bottom to top.
 - b. Left to right and from bottom to top.
 - c. Right to left and from top to bottom.
 - d. Left to right and from top to bottom.
-
- 2. Wiring diagrams are very important tool for the technicians and they use them to:
 - a. Know the sequence of operation.
 - b. Represent the major components in an electrical system
 - c. Locate a particular component or wire in a panel
 - d. None of the above.
-
- 3. Schematics are very important tool for the technicians and they use them to:
 - a. Determine the sequence of operation in a circuit.
 - b. Represent the major components in an electrical system
 - c. Locate a particular component or wire in a panel
 - d. None of the above.

SECTION D

Study the diagram shown in the next page and answer the following questions:

- A. What type of drawing is this?
- B. What is the main protection of transformer?
- C. What is the transformer vector group?
- D. What type of tape-changer used with this transformer?
- E. List the relays that trips the high voltage side CB ©.
- F. What is the percentage impedance of the transformer?

REVIEW EXERCISE

G. Which protection trip the low voltage side CB (T) only?

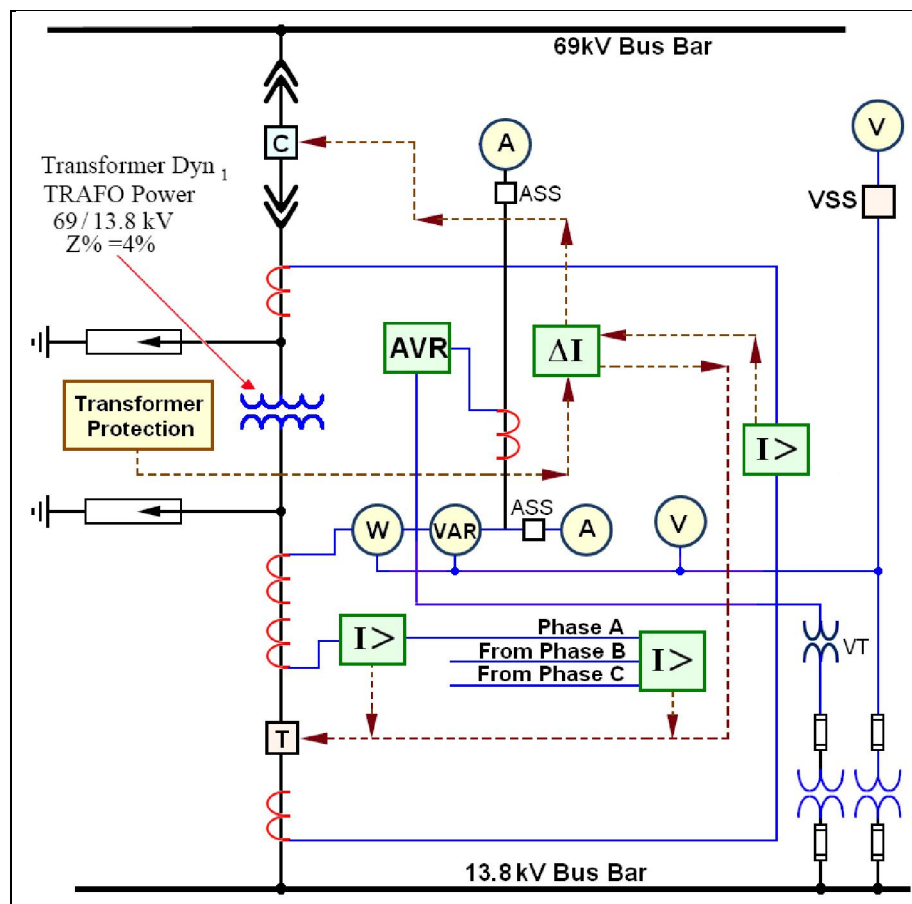
H. How many transformers are located on the 13.8 KV bus bar? Give the function of each.

I. Give the name for this symbol



J. Give the ASDFN for each of the following symbols used in the diagram:

ΔI		ΔT	
$I >$		T	



II) Study the diagram shown in the attachment drawing Figure (6) and answer the following questions:

1. If any of the magnetic contactors controlling the operation of the CB carriage is energized, does the CB will accept closing signal or not?
2. When is the anti-pumping relay energized and when is it de-energized?
3. What “N” stands for and when does it operate?
4. Where is the location of 63-X1?
5. When is 63-X1 energized and when is it de-energized?
6. When the mode selector switch in the remote position is, does this affect tripping the CB by protection?
7. What are the main points you have to check when reading of DC schematic for a CB closing Circuit?



LESSON 2.2

RELAY TESTING

LESSON 2.2

RELAYS TESTING

OVERVIEW

This lesson discusses the types of tests applied on the protective relays at the customer site, including acceptance test and installation test. The lesson scopes out the commissioning for different types of relays.

The lesson also focus on the primary injection tests for the protective relays and there requirements.

OBJECTIVES

Upon completion of this lesson, the trainee will be able to:

- List types of tests performed on protective relays.
- Identify the acceptance tests for relays.
- Verify the installation tests for relays.
- Demonstrate the procedure for relay commissioning.
- Illustrate the requirements of relay tests and commissioning.
- Perform primary and secondary injection tests for protective relays.

INTRODUCTION

Protective relays are always concerned with protective scheme, and cannot therefore readily be tested under normal system operating conditions. This situation is aggravated by the increasing complexity of protective schemes and relays. The actual operating time of protective relays is extremely small over a long life on the power system. Thus, we must think, “will the relay operate properly if a fault situation occurs”. So testing of relaying schemes is very important.

TYPE OF TESTS

There are four classes of tests:

- Acceptance tests
- Installation tests
- Maintenance or functional tests
- Repair tests

The last two tests will be explained in the next lesson

ACCEPTANCE TESTS

These tests could be classified to:

1. New product first time applied.
2. Tests on each product received.

Acceptance tests are done once and generally in the laboratory. These are separated into the two types:

1. New Products have not been previously used; extensive testing on a sample may be desired to gain experience and knowledge and/or additional technical information.
2. On Each Product Received from the Manufacturer should be streamlined to a minimum including only the important practical checkpoints to assure that the product is what the manufacturer specifies.

INSTALLATION TESTS

Installation tests are field tests to determine that the installation will perform correctly in actual service. These are not normally repeated on any given installation unless an incorrect operation has occurred. Most frequently they are performed by simulated tests with the secondary circuits energized from a portable test source.

Other methods include:

1. Simulated tests using primary load current and voltage.
2. Operating tests with the primary energized at a reduced voltage.
3. Staged fault tests.

Staged fault tests are actual faults and this method is limited and not used in usual cases.

Commissioning Tests

When any protective scheme is newly installed it must be fairly checked and tested before placing it in to operational services. Commissioning causes a very wide range of activities, as we shall study in this lesson. In many cases protective schemes forms part of the completely new power installations or perhaps an extension to an existing sub-station or generating station.

Commissioning of the protective equipment must be coordinated with the commissioning of primary equipment such as transformers, generators, switchgear, transmission lines, and feeders and so on. Several different groups of personnel will be involved in the overall task. The personal involved in these tasks are:

- Installation contractors.
- Equipment manufacturers.
- Power company representatives.

The power company personnel will be from different departments, each with a specific field of responsibility. The engineering and constructional department's duties are to inspect, and test the primary equipment. The protection personnel duty is to test

and commission the protective scheme. The operator's duties are to determine switching procedures, and take over operation of the installations.

Detailed planning before the commissioning is necessary to ensure that the commissioning tests are performed in a safe logical order and that no item is overlooked. It is essential that all safety rules and procedures be strictly observed at all times.

The work should be performed after acquiring any necessary permits, typically a permit to work, or a permit to test. All documentation and report forms must be ready as it is essential to keep accurate records of all tests and operations. The recorded figures provide a benchmark for comparison of future test results. This information can also provide the bases of a claim against manufacturers or contractors in the event of unacceptable work.

The overall objective of the commissioning tests is to prove that:

1. The equipment has not been damaged in transit.
2. The equipment has been correctly installed.
3. The protection scheme performs according to specifications and that the design and specifications of the protection system is appropriate for the installation it is required to protect.
4. The equipment is safe to connect the new installation to the power system.

Most power companies continuously update their procedures for testing and commissioning new installations. Before any equipment can be energized it is essential that the related protective schemes be tested and placed in service, even though further adjustment may be required later.

Examples of “Procedures for Testing and Commissioning”

Commissioning Tasks Overall

BREAKERS

- Tighten all connections
- Make necessary time-adjustments.

- Pass primary current through all current transformers and check all secondary taps and polarity.
- Test current transformer excitation on all taps.
- Check all internal wiring.
- Check all pressure switches and alarm points adjust if necessary.
- Conduct secondary injection test

Transformers

- Tighten all internal connections.
- Make turns ratio checks on all taps, primary and secondary.
- Conduct secondary injection test.
- Check excitation and polarity of all current transformers.
- Electrically check all pumps and fans controls and alarms.
- Electrically check tap changer controls for tap position and over-travel alarms.
- Check all temperature gauges, alarms, etc.

Bus PT's, Line PT's and Coupling Capacitors

- Conduct secondary injection test.
- Wire check secondary connections to secondary fuse panel

Lightning Arresters

Conduct secondary injection test.

Cables

Megger test and check all cables from switchyard terminal blocks to termination point in station building, couplers, differential junction boxes, and bus or line PT's secondary fuses.

Battery Charger

Install and adjust battery charger to station voltage.

Switch Board

- Tighten all connections to terminal boards and relay cases.
- Do point-to-point wires check of relay panels to wiring print, elementary drawings and actual wiring as done by the manufacturer.

Relays

- Check internal condition of relays for loose connections, loose parts, and foreign material.
- Calibrate relays to settings as received from system protection.
- Test all auxiliary relays as to coil resistance, pick-up, and dropout voltages, and contact make-and-break time.
- If necessary, adjust to limits prescribed by System Protection.

Current Passing

Using three-phase resistive load pass secondary current in all relaying and metering schemes:

- Apply three-phase voltage to the relaying and metering schemes.
- Using a phase meter, phase all relaying and metering schemes.

Tone and Carrier Circuits

Make necessary adjustment and alignment tests on power line carrier and tone circuits.

Motor Operated Load Breaks and Circuit Switchers

- Check internal parts for tightness.
- Check all auxiliary switches and connections.
- Check motor circuit for limit switches, etc.
- Operate switches from remote and switchboard controls.

Operational Tests

Make a complete operational test of all relaying schemes, including trip test to remote stations.

Supervisory Control

- Check internal wiring or loose connections and wire correctness.
- Check cable connections to main control board.
- Make complete operational check of supervisory control from master, including opening and closing of breakers.
- Make check of metering and alarm circuits to master end.

Enunciator Panels

Check every alarm point in station to its associated enunciator drop.

Switchboard Metering

Calibrate all switchboard metering and transducers for remote metering.

Energizing

- Energize equipment and make phasing tests in relaying and metering schemes at first point in each current transformer circuit.
- Update field checks prints and returns to Engineering Department.
- Complete relaying books, charts, etc.

2) Initial Energizing

- a) Obtain the proper authorizations from Power Control/Regional Control Centers and perform the required switching and mark-up activities.
- b) Perform a visual inspection of the equipment to be energized where practical (line, bus, bank, etc.)
- c) Transformers must be energized with no connected load. See Station Apparatus Procedures Manual for special energizes monitoring procedures. All transformer protective relays shall be operational.
- d) Buses must be energized from a single point and isolated from load of any kind. The bus differential relays must be operational.
- e) Lines not directly connected to generators shall be energized from one end initially, and then the other end. Lines connected to generation must be

energized only from the end remote to the generator. For initial line energization, instantaneous non-directional line protection must be utilized.

- f) Inform coordinator with written documentation that the conditions for energization have been met.

In-Service Tests

- a) Directional Line Protection:

When directional overcurrent and directional distance measuring relays are employed, verify that the relays display directional characteristics by simulating faults both within and outside the prescribed characteristic. Just after station energization, employ standard tests for directionality using load current and/or voltage in conjunction with appropriate instruments.

- b) Current or Voltage Bus Differential:

As soon as possible after the station is carrying normal load, verify by actual measurement that the differential relay current or voltage is balanced at the summation point.

- c) Transformer Current Differential:

As soon as possible after the bank is carrying normal load, verify that the differential relay current at the summation point is within the allowable limits established by the instruction manual.

- d) Breaker Failure Protection:

After individual calibration of auxiliary relays and timers, the total scheme timing should be checked with a sequence of events recorder. The tape must become part of the station test records after it has been approved by Station Protection Design.

- e) Generation Protection:

During the reduced excitation short-circuit tests, verify operation of all generator protective relays and check that the generator differential current at the summation point is within limits established in the relay instruction manual. With the generator synchronized to the system, verify the directionality of any directional power relays, distance relays, overcurrent relays or other directional relays associated with the unit by simulation or using actual current and/or voltage.

RELAY TECHNICIANS ACTIVITIES DURING COMMISSIONING

The followings are a brief of the relay technician activities during commissioning:

- 1) Make planning checklist.
- 2) Review the primary block diagrams.
- 3) Perform visual inspections of the primary equipment's installations.
- 4) Review protective scheme schematics (AC & DC).
- 5) Checking that the secondary wiring is correct.
- 6) Review the circuit breaker test results.
- 7) Testing of the CT's and PT's.
- 8) Perform secondary injection tests.
- 9) Perform primary injection tests.
- 10) Perform functional testing of tripping circuits.
- 11) Perform functional testing of alarm and enunciators circuits
- 12) Perform phasing of the primary circuits.
- 13) Perform testing on power supplies.
- 14) Perform on-load testing once the primary equipment has been energized.
- 15) Perform review of equipment instructional manuals.
- 16) Perform testing and calibration of protective relays.
- 17) Review availability of appropriate test equipment.
- 18) Review safety requirements.

Before commissioning, the primary high voltage equipment is de-energized and will be grounded at several points. As in all cases, work in live area must be done under appropriate permits. Clearly one of your job as a relay technician is to become familiar with the installation. Regular trips should be made to the site during the construction period. This will allow you to be more acquainted with the physical layout of primary equipment, control panels, relay panels and so on. Particularly note the locations of CTs, PT's and the respective wiring. Often several sets of CTs are located in switchgear bushings or transformer bushings. Make sure that each CT is connected to the right device, be it metering, indications, or protective relay.

Commissioning Secondary Circuits Wiring

It is essentially that you thoroughly review and understand the schematic diagrams for each of the protective schemes. Trace thoroughly these diagrams to understand of the protection system. If you have any question as you probably will have, make sure that you discuss this with your supervisor. You may spot something that may cause problem later.

You should have a separate as-built diagram for each protection and control loop. This is quite different from the wiring diagram that it is used by the contractor for installations. These installations wiring diagram are really graphical in nature, and one diagram says to a relay panel may include several hundred connections and involved a multiple number of individual loops

You should check the wiring diagram against your schematics to prove that the wirings really do achieve what it is set out to do.

When the installation of secondary wiring has been completed, it should be thoroughly checked to make sure that it complies with the wiring and schematic diagrams.

Remember that part of the area may be operational and therefore energized, so you will need to take out a permit from operator. Make sure that all terminal connections are right, and that fuses and links are properly wired and rated.

Check nameplates on all control panels, relay panels and equipment. In outdoor substations, make sure that the secondary equipment is weatherproof and that any specified heating and ventilation are in service. Point to point continuity of the secondary wiring should have already checked out by the contractor, but in some, the insulation resistance Test, that is, IR tests, must be carried out usually in conjunction with the contractor. Before commencing the IR test, make sure that the wiring is isolated, that is no equipment is connected. Also, ensure that all wiring to ground are removed. Check the insulation resistance to ground and between each separate circuit. The insulation resistance should be between one (1) and ten (10) Megaohms using a 500-Volt Megger. Finally when testing of secondary wiring is completed, the permanent ground should be reconnected.

Remember this wiring is usually grounded at one single point only. Make sure it is so. The DC system can now be energized from the battery and rectifier, when this is operational. This will enable operation of the circuit breakers to be checked and other functional tests to be carried out.

1.2.5 Commissioning Instrument Transformers

A) Voltage (potential) transformers (pt's)

During these preliminary tests it is usually convenient to test the VT's for:

- Insulation Resistance Test.
- Polarity Test.
- Turns Ratio Test.

Before conducting the tests on **PT's**, both the primary and secondary windings must be isolated from external circuits. The insulation resistance is checked between windings and between each phase and ground.

One simple method for checking polarity is by performing a “flick” or “kick” test on each phase separately as shown in Fig. 2.2-1. A low voltage DC battery is connected across the primary, high voltage winding with the circuit interrupted by a push button.

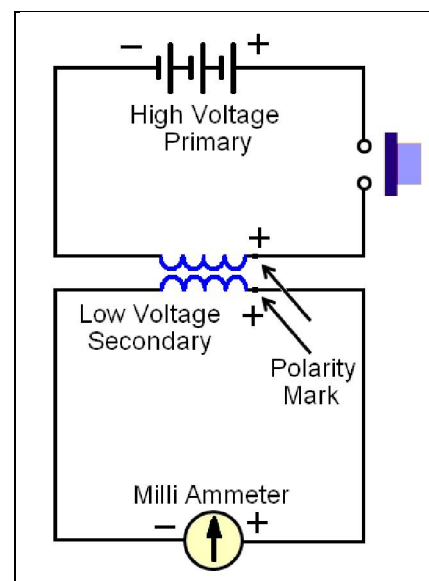


Fig. 2.2-1 Polarity Test

The positive side of the battery is connected to the polarity marked terminal. When the push button is closed, if the ammeter will flick to the positive side, this will indicate that polarity markings are correct.

The ratio test, Fig. 2.2-2, is carried out by applying a relatively low voltage, say 220V or 480V, to the single-phase primary (high voltage) side of the transformer, and accurately measuring the secondary voltage. From the two readings ratio can be calculated.

For this test the primary voltage supply should be fused in both lines just in case there is a fault in the new transformer.

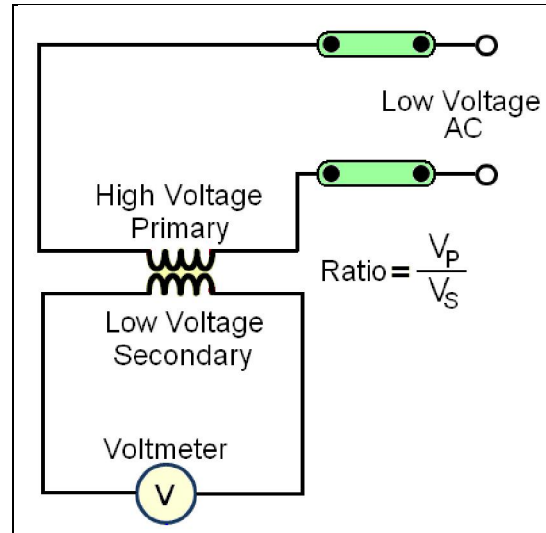


Fig. 2.2-2 Ratio Test

PRIMARY INJECTION

This type of test involves the entire circuit, current transformer secondary, relay coils, trip and alarm circuits, and all intervening wiring are checked. There is no need to disturb wiring, which deviate the hazard of open circuiting current transformer, and there is generally no need for any switching in the current transformer or relay circuit. Primary injection is usually carried out by means of a portable injection transformer (Fig. 2.2-3), arranged to operate from the local main supply and having several low voltage heavy current windings. These can be connected in series or parallel according to the current required and the resistance of the primary circuit.

The injection transformer is usually rated at about 10kVA and has a ratio of 250/10 + 10 + 10 + 10 volts. This permits currents up to 1000 A to be obtained with the four secondary windings in parallel and up to 250 A with the windings in series. The best method of controlling the injection transformer current is to use a tapped reactor similar to that in secondary injection equipment, or a heavy current (40A) variable autotransformer. The use of resistors for current control causes a great deal of power to be dissipated unnecessarily.

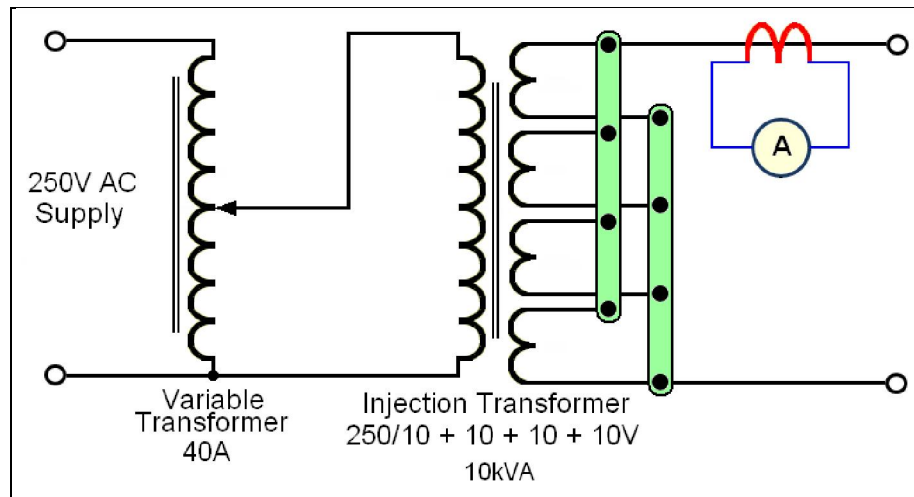


Fig. 2.2-3 Primary Injection Test Set

If the main current transformers are fitted with test windings, these can be used for primary injection instead of the primary winding. The current required for primary injection is then greatly reduced and can usually be obtained from secondary injection equipment shown in Fig. 2.2-4

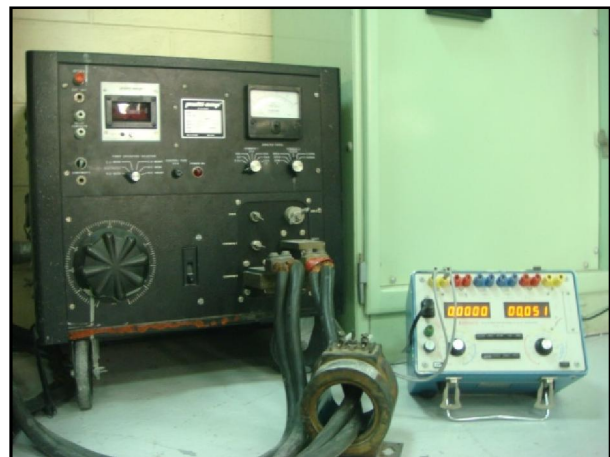


Fig. 2.2-4 Primary Injection Test Set

Many companies check out CT connections by primary injection tests.

In this method low voltage test current is passed through the primary conductors and measurements are taken on the secondary side to prove that the CT connections are correct.

Note

Before commencing any primary injection test, make sure, that the primary circuits are isolated and available for test purposes. Take out a “permit to test” from the operators. You may have to remove temporary grounds from the primary circuit. The diagrammatic arrangement in Fig. 2.2-5 shows three CTs, each connected to its own overcurrent relay, with the residual passing through a ground fault relay at the relay panel, a low impedance milli-ammeter is placed in series with the ground fault relay.

Test current is passed through the primary of one CT only, say, the A-phase, and the magnitude of secondary current is indicated by the milli-ammeter. The value of test current will depend upon the capacity of the test set and the CT ratio.

With a CT ratio of, say, 500:5, a primary test current of 10 amperes would provide a secondary value of 100 milliamps. With a CT ratio of 3000:5, the same primary current would provide 16.6 milliamps. The CT ratio can be checked from these readings. This test should be carried out on all three CT's.

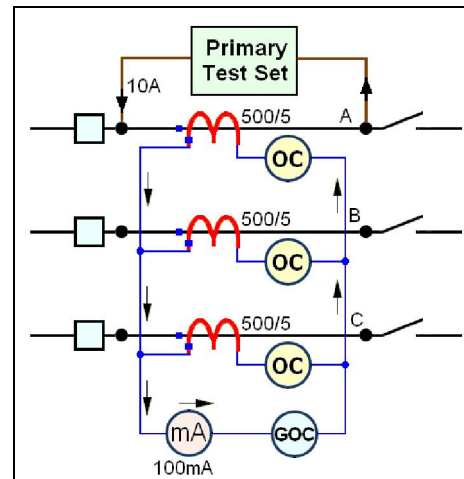


Fig. 2.2-5 Testing of CT Ratio by Primary Injection

The next test is to ensure that the CT's are connected the right way around, that is to say they are in balance.

For this test a temporary short circuit is placed across the primary conductors (Fig. 2.2-6).

In this particular example, test current is passed through the A-phase CT primary conductor and then back through the B-phase CT in the opposite direction.

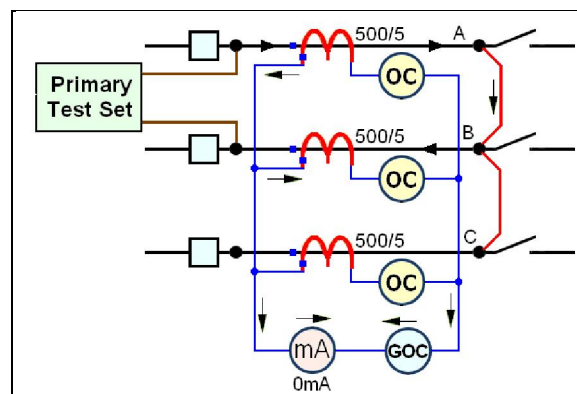


Fig. 2.2-6 Testing CT Balance by Primary Injection

The resultant CT secondary currents should cancel each other out if the CT connections are correct, that is, the residual current, which is being measured by the milli-ammeter, should be zero. If one of the CTs had been connected the wrong way around, the secondary currents would be additive instead of opposing and canceling each other out. Consequently, the residual current indicated by the ammeter would be about twice the value in Fig. 2.2-6.

Clearly, at these low values of secondary current, great care must be taken in order to obtain accurate readings. Some companies use a larger test set in order to provide a higher value of primary test current, thereby checking operation of the relay itself in addition to verifying CT connections. Typically, the test set will be rated at, say, 10 kVA, with the capability of providing up to 1000-amps at 10-volts.

PRIMARY INJECTION TEST FOR GENERATOR DIFFERENTIAL PROTECTION

Fig. 2.2-7 shows the primary injection test for generator differential protection. Primary current is passed through one CT only and the value increased until the corresponding relay operates. This value of test current indicates the value of fault current required in the primary to operate the relay. This sensitivity test is repeated for each separate phase.

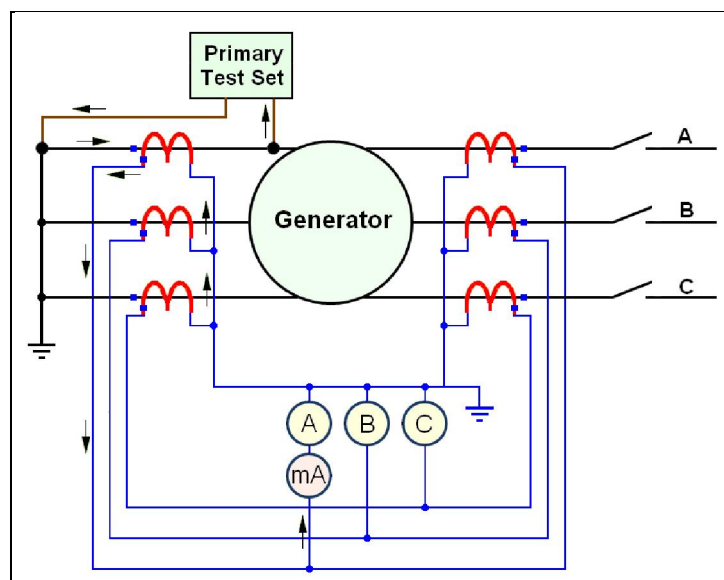


Fig. 2.2-7 Checking Current Required to Operate Differential Relay

To check the balance of these relays it is necessary to connect a short circuit (if the windings are not connected together at an appropriate point) and then circulate test current between two-phases at a time, see Fig. 2.2-8. The return residual current should be zero or close to zero. A similar set of tests would now be performed on the CT's at the other side of the generator.

However, how can we check the differential relay for stability? The most common way of performing this test, particularly where a new generator is being commissioned is to place a short circuit across the generator terminals and run the machine at very low excitation.

This allows load current to be passed through the generator windings at low voltage and for a very small amount of power input from the prime mover. Indeed, this is also the established method for drying out the generator winding. It also provides us with an excellent opportunity to check secondary current input to all of the generator protection devices.

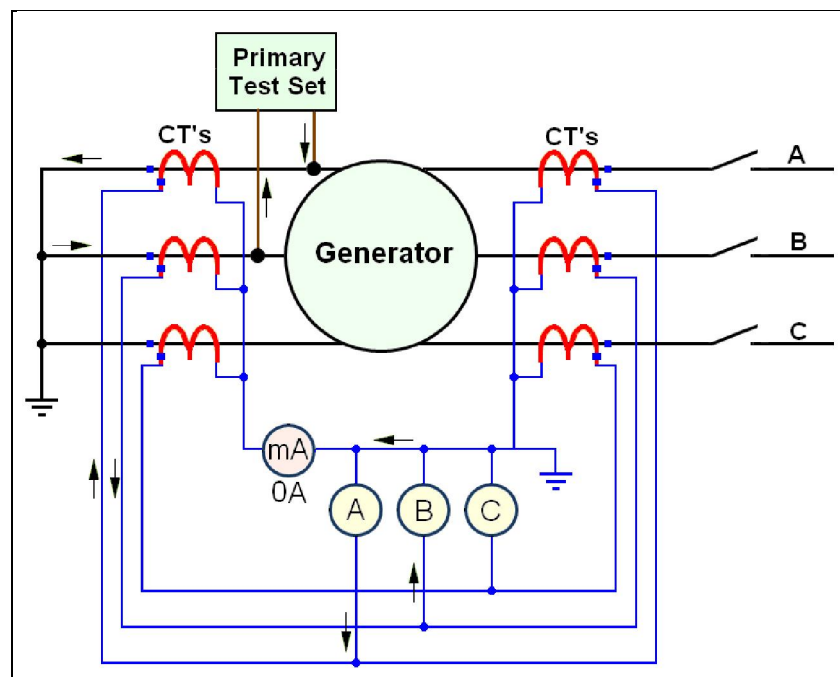


Fig. 2.2-8 Checking Balance between Relays

Primary Injection for Transformer Differential Protection

When conducting the stability test on large high voltage power transformers, it is likely that the test set will not have sufficient capacity to pass adequate primary test current through the transformer impedance to trip the relay. The test is usually performed by placing a short circuit across the low voltage side of the transformer and energizing the high voltage windings from a three phase low voltage supply, say 600-

volts (Fig. 2.2-9). This will not supply enough current to trip the relays but, by carefully measuring current flow at the appropriate **CT** links, we can check:

- **CT** ratio
- **CT** polarities
- **CT** circuit wiring
- wiring of auxiliary **CT**'s
- wiring of differential relays

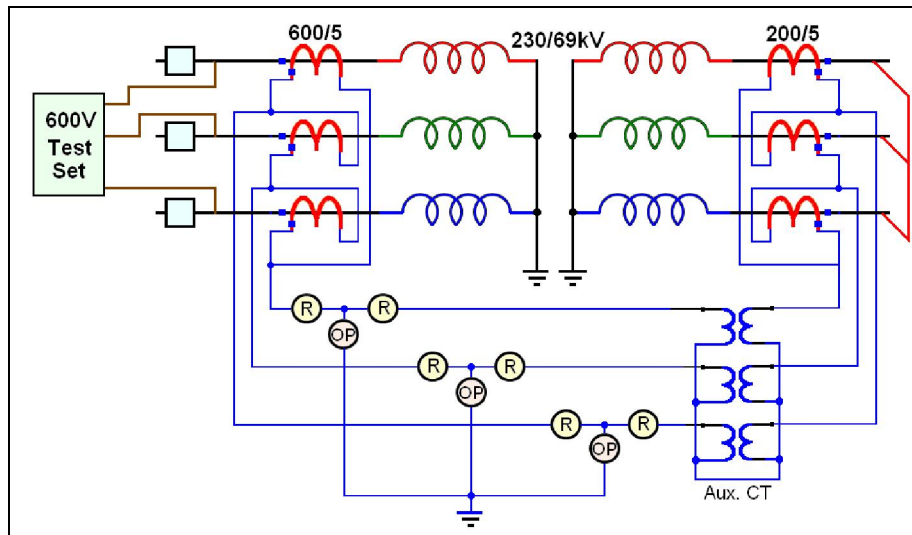


Fig. 2.2-9 Stability Test on Power Transformer

SECONDARY INJECTION

Relays are usually tested in place by secondary injection. In this test, the relay is isolated from its **CT**'s and **VT**'s, and **AC** current (and voltage where required) is injected directly into the relay to simulate fault conditions, see Fig. 2.2-10. Alternatively, the relay may be withdrawn from the panel and tested on the bench. However, it is usually recommended that relays be tested in place (or at least in a test case) as the case may change the relay's characteristics.

Remember whenever a relay is withdrawn from the panel or the **CT** leads are disconnected in any way, it is essential that a short circuit be connected across **CT** secondary terminals. If this is not done, a dangerously high voltage could appear at the open circuited terminals. Even with zero load current in the primary, high voltage could be inducted into the secondary from electrostatic sources.

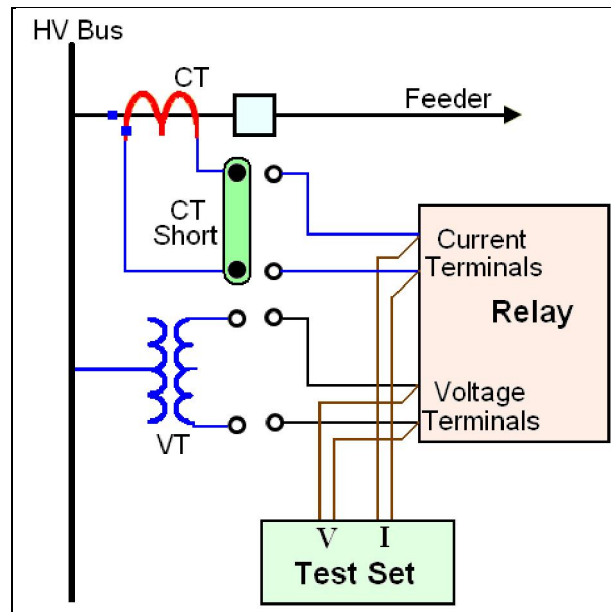


Fig. 2.2-10 Secondary Injection Testing at the Relay Site

SECONDARY INJECTION AT CT'S AND VT'S

As shown in Fig. 2.2-11, is to apply secondary injection into the relay CT and VT inputs, preferably at the CT and VT secondary terminals themselves. Links and blocking switches are often provided for this purpose. Injection of the appropriate value of secondary current and voltage to simulate differing fault conditions allows simultaneous testing of the secondary wiring. The protective scheme, the protective relays, auxiliary relays, auxiliary switches, and the resultant functions.

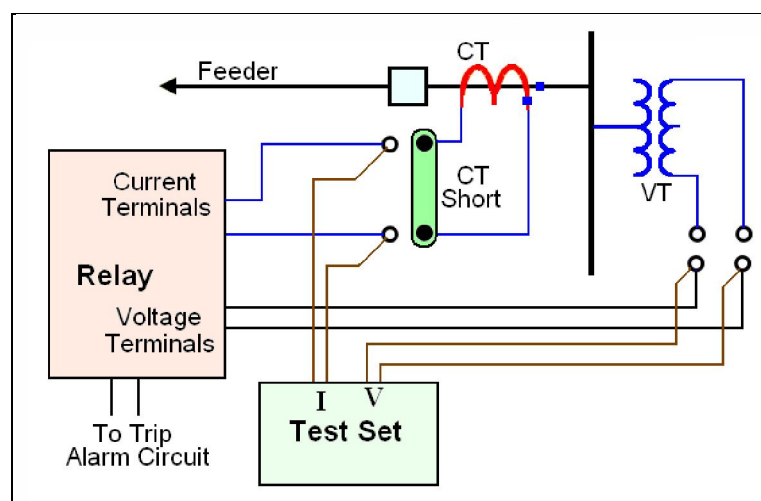


Fig. 2.2-11 Secondary Injection Testing at the Relays Site

TYPICAL RELAY TEST EQUIPMENT

Test Equipment

Testing equipment varies depending on where the test is done, either in the test laboratory or at the relay location. The following equipment should be available in the laboratory and/or in the field.

1. Variable auto-transformer, 120 volts, 5, 20 A continuous rating.
2. AC voltmeter
3. DC ammeter, 0.5 – 20 – 50 A
4. Phase angle meter
5. Auxiliary current transformer
6. Electronic timer
7. Phase shifter
8. Oscillograph
9. DC voltmeter
10. Frequency generator
11. AVO meter
12. AC source
13. DC power supply
14. Relay tool kit
15. Test plugs
16. AC ammeters 0.5, 2, 5, 10, 20, 100, 200 A
17. Non-inductive load (resistors in parallel)
18. Three-phase sequence indicator
19. Auxiliary relay, 2 make, 2 break electrically operated and electrically or hand reset.

Test Plugs and Test Switches

Test plugs

Test plugs are used in the relay circuits so that connections can readily be made to the test equipment without disturbing wiring of the relaying schemes, see Fig. 2.2-12.



Fig. 2.2-12 Relay Test Plug

Test plug as shown in Fig. 2.2-13, 14, 15 is separated by an insulating strip. The relay circuits can be completely isolated from the switchgear wiring when the test plug is inserted.

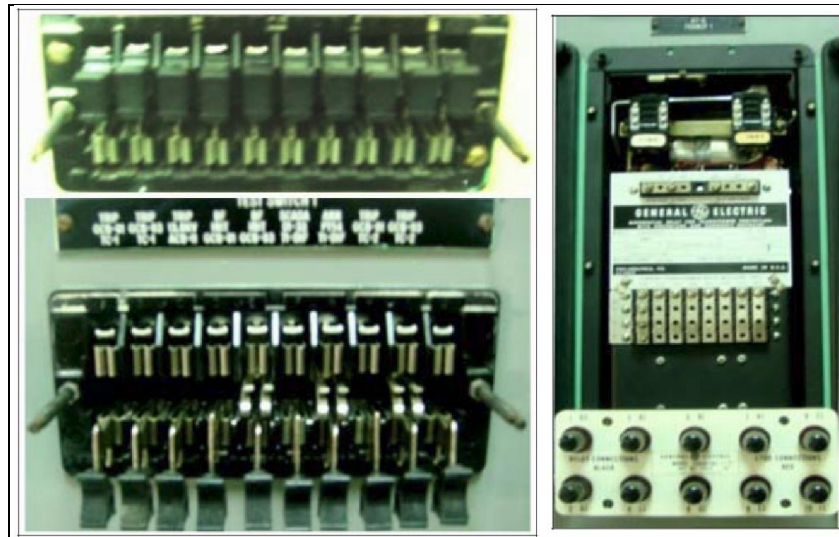


Fig. 2.2-13 Relay Terminals and Test Plug



Fig. 2.2-14 Test plugs (General Electric)

It must be remembered, however, that the current transformer shorting switches, fitted to the draw-out chassis to prevent the current transformers becoming open-circuit if the relay is ever withdrawn on load, remain open-circuit when the test plug is inserted. It is therefore essential that CT shorting jumper links are fitted across all appropriate live side terminals of the test plug BEFORE it is inserted.

With the test plug inserted in position, all the test circuitry can now be connected to the isolated. 'Relay side' test plug terminals.

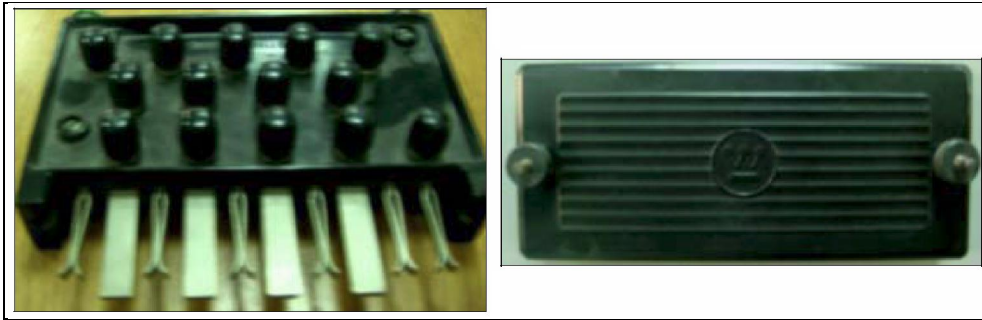


Fig. 2.2-15 Test Plugs (Westinghouse)

REVIEW EXERCISE

1. List 4 checks to be performed on **CT's** during commissioning:

2. Generally, how are **CT's** connections checked by secondary injection? What do the tests prove?

3. Generally, how are **CT** connections checked by primary injection?

4. In Fig. 2.2-4, if one of the **CT's** under test had been connected “the wrong way around” (that is, the polarity is reversed), what residual current would you expect?

5. In Fig. 2.2-7, what are the items that can be checked by carefully measuring current flow at the CT links?

6. Describe the test performed in Fig 2.2-9.

REVIEW EXERCISE

7. What parts of the circuit are tested in Fig. 2.2-9?

Complete the following with the suitable words:

8. Relays are usually tested in place by secondary injection. In this test the relay is _____ from its **CT's** and **VT's** and **AC** _____ and _____ is injected into the relay to _____ fault conditions.

TASK 2.2-1

CHECKING CURRENT TRANSFORMER TURNS RATIO

OBJECTIVE

Upon completion of this task, the trainee will be able to check turns ratio of current transformer using primary injection test set.

EQUIPMENT, TOOLS & REQUIREMENTS

1. Primary Injection test set.
2. Window type current transformer.
3. AC ammeter, (1-5) ampere range.
4. Clamp ammeter.
5. AC power supply 230 volts.
6. Personal safety equipment as recommended in relay workshop.

This task is preferred to be applied on high voltage switchgear, during window type CT, which connected on 34.5kV bus bar.

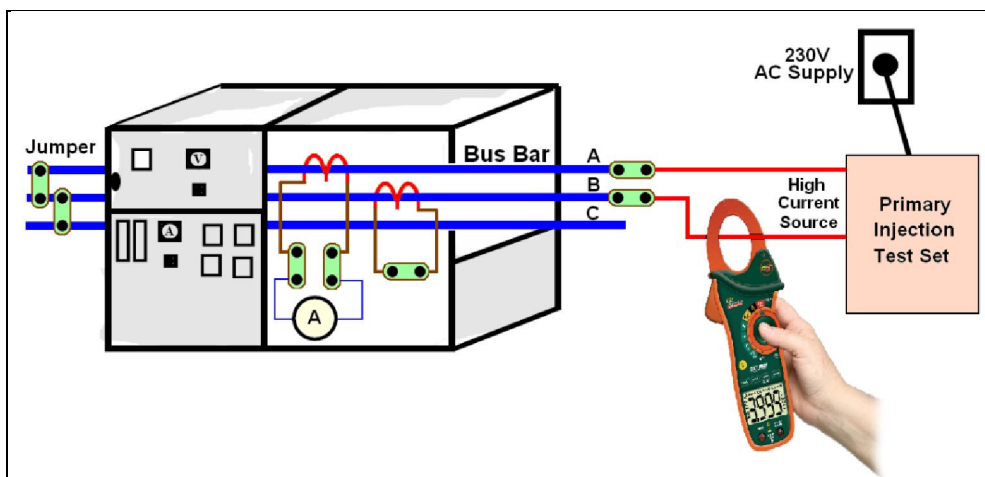
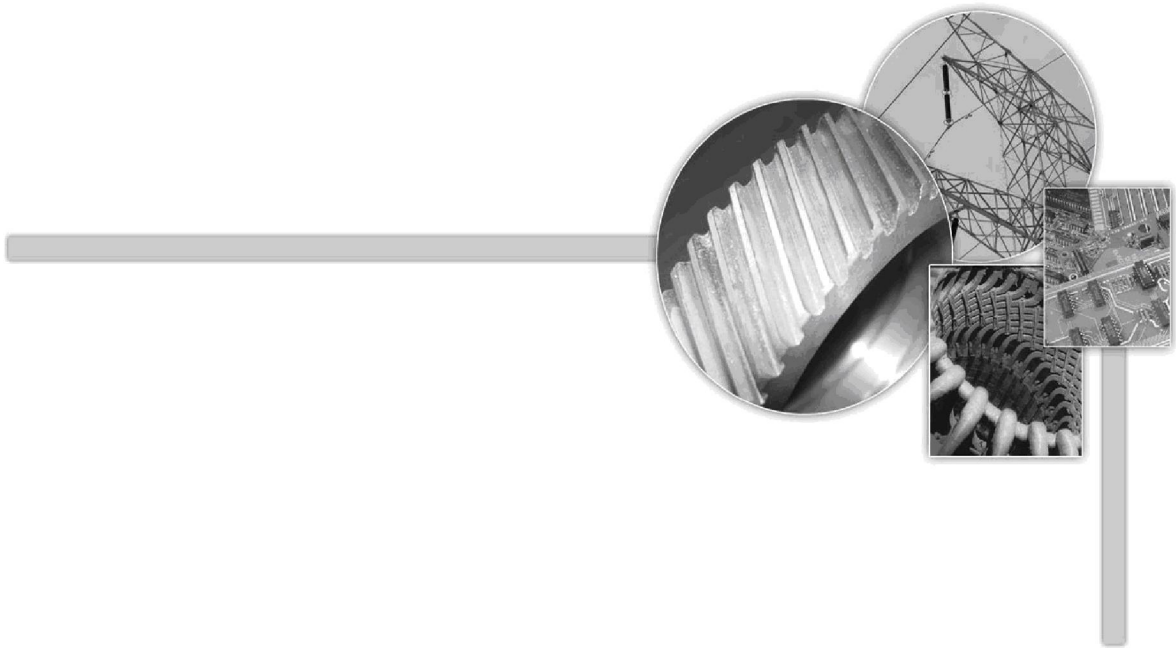


Fig. 1-1 Connecting High AC Current to Bus Bar

PROCEDURE

1. You must be sure that the 34.5kV bus bar is disconnected from any high voltage.

2. Connect a jumper between phases A and phase B at the bus bar terminals.
3. Identify the three CT's connected on the bus bar.
4. Make jumper on the secondary of the CT that connected with phase B.
5. Connect AC ammeter in series with the secondary circuit of CT that connected with phase A, and be sure that the CT secondary circuit is closed.
6. Connect bus bar terminals A & B to the current source of primary injection test set.
7. Connect the primary injection tester to 230V AC supply.
8. Switch on the tester, and connect the clamp ammeter to read the primary current of phase A.
9. Raise the primary current from the injection tester until the clamp ammeter read appropriate value to let AC ammeter read an obvious current value.
10. Monitor and record the secondary current in the ammeter.
11. Divide the primary current of the clamp ammeter on the CT secondary current of the AC ammeter to get the turn's ratio.
12. Turns ratio = I_p / I_s
13. Repeat the last procedure, using phase B.
14. Lower the primary current until zero.
15. Switch off the primary injection test set.



LESSON 2.3

FUNCTIONAL & IN-SERVICE TEST

LESSON 2.3

FUNCTIONAL & IN-SERVICE TEST

OVERVIEW

This lesson discusses the functional and in-service tests for protective relays. It lists all the applicable tests that can be done on the protective relays with its procedure and cautions.

OBJECTIVES

Upon completion of this lesson, the trainee will be able to:

- Verify the overall protective relay tests.
- Demonstrate procedure of functional tests.
- Identify energization and in-service tests.
- Perform necessary tests for O/C time relay.

INTRODUCTION

Unlike conventional testing which is mostly procedural, functional testing is unique to each device type. Input signal levels, current loading conditions, supply ranges, reliability, and functionality are dependent upon the characteristics of any given circuit. It may be best to approach the subject from a top-level view, then at a later time focus on testing a specific device. This approach will enable us to understand the general issues common to all functional tests as well as the device specific issues. The majority of users perform maintenance or functional testing at least once a year.

Maintenance or functional testing is done in the field at regular intervals. These intervals vary among users depending on:

1. past experience
2. type of protective relays employed,
3. voltage class of the power system,
4. supporting systems, among others
5. importance of equipment being protected

CLASSES OF RELAY MAINTENANCE

1. Inspection and burnishing of contacts (electromechanical relays).
2. General inspection (foreign matter removed, screws checked for tightness, printed circuit boards properly inserted, covers cleaned, etc.).
3. Adjustments checked.
4. Breakers tripped by manual contact closing.

REPAIR TEST

Repair testing as the name implies involves re-calibration after major repairs have been made. Such tests are performed in the laboratory. Many minor repairs frequently are done during maintenance tests and need not involved complete re-calibration tests. The physical condition of any relay is normally checked as it is removed from its packing. A further examination should be made on the installation before performing any electrical tests. The relay panel and general area should be clean. In particular, the relay case must be thoroughly dusted before the cover is removed. Examine the

internal condition of the relay, for signs of damage. Make sure that all moving parts operate freely, and that contacts make correctly. All terminal connections and other screws should be tightened. Examine the wires to make sure that none is broken. The target mechanism should be checked for operation and re-setting. Report any discrepancy so that claims can be made to the supplier or contractor. It is to be expected that, before leaving the manufacturer's works, each relay will have been thoroughly tested to ensure that it meets specification. However, it is still necessary to perform functional tests on site with the relay in its installed location, and also to calibrate the relay for its particular circuit.

Many different types of test sets are available to supply adjustable current and voltage to the relay. The test equipment normally includes a phase shifting transformer to allow variation in voltage/current (phase) angle as well as magnitude. Make sure you are familiar with the test sets used by your company.

Some of the following tests may be performed:

- insulation resistance test
- the zero check
- the inverse time-characteristic
- operation of the target and seal in circuit
- other tests particular to the type of relay
- the value of pick-up current at different tap settings

The precise test and calibration procedure for each specific relay is explained in the manufacturer's instruction manual. You must also follow **SEC** procedures in performing any test and calibration activities.

Maintaining accurate records is vital. All test results must be carefully noted and final calibration settings registered. Make sure you are familiar with your own company's documentation requirements.

FUNCTIONAL TEST

After the relays have been checked out and calibrated, functional tests of the tripping circuits must be performed. The objective of function tests (or operation tests) is to verify that when a particular relay operates, its output produces the desired action such as:

- Tripping of one or more breakers.
- Blocking operation of certain breakers.
- Initiating appropriate alarms and enunciators.
- Completing a permissive circuit to “enable” other circuits to function.
- Triggering operation of a power line carrier circuit or other communication channel.

In order to perform functional tests the relay panel must be energized with secondary **AC** and **DC** voltage.

One simple method of performing functional tests is to operate the relay mechanically by physically closing the appropriate contacts. In the simplest circuits this relay output will apply **DC** to the tripping circuit and so cause the appropriate breaker to open and initiate the corresponding alarm and enunciator. In order to prevent repeated operation of the breaker during testing, the local trip circuit is usually isolated using isolation links or blocking switches, and the associated trip signal is measured instead.

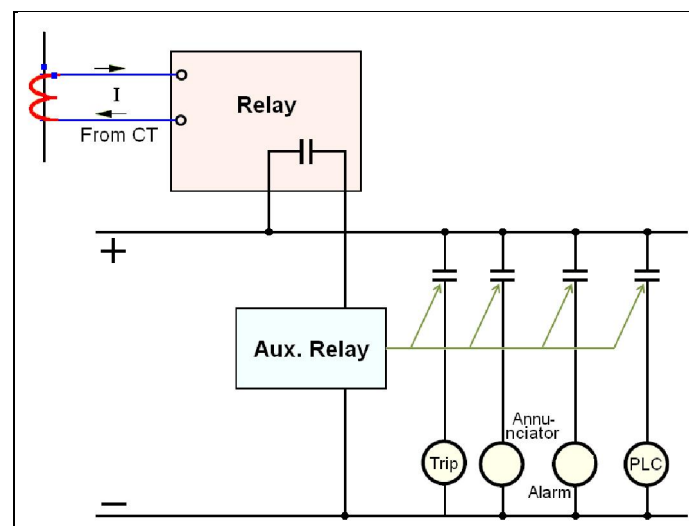


Fig. 2.3-1 Checking Auxiliary Relay

In many cases, the relay output energizes an auxiliary relay, which has multiple contacts (Fig. 2.3-1). In this situation, there would be multiple output functions to check by either observing the resultant action, or, alternatively, by measuring the output signal to each function. Each auxiliary relay should also be tested for operating time and reset time to make sure that it complies with specification.

For some types of relays, particularly solid state relays, it may not be easy or even possible to operate the relay contacts mechanically. One way around this problem is to simulate the output signal by isolating the relay and injecting the appropriate DC voltage into the output circuit.

In any particular protection scheme, several protective relays may be involved and several secondary inputs required simulating fault conditions. Each functional test will need careful, detailed planning before implementation.

Functional testing must also be performed on other related items, which are not truly part of the protection system. Depending upon the particular installation, these items may include:

- Remote and local controls
- Remote and local indicators
- Chart recorders such as oscillograph.
- Alarms and enunciators for all equipment
- Automatic controls for transformer pumps and fans
- Auxiliary equipment and controls for breakers
- SCADA equipment
- Battery chargers
- Metering
- Carrier and tone equipment

As an example of pre commissioning tests on inter tripping devices, we will look at power line carrier. Typically, the tests will include the following at each end of the line:

- Checking of power supplies to the transmitter receiver unit.
- Adjusting the transmitter output and receiver sensitivity.
- Checking on-off operation and frequency shift.
- Tuning the line traps.
- Tuning the line coupling circuit.

Checking signal attenuation (that is loss of signal strength) along the line under different conditions that is:

- a) With the line ungrounded.
- b) With the line grounded beyond the line traps.
- c) With the line on-load.

ENERGIZATION AND IN-SERVICE TESTS

Before energizing primary equipment the commissioning team must make sure that:

- All work has been completed.
- All temporary grounds are removed.
- All permits to work are cleared.

All protection relays should be in service, even though further adjustments may have to be made. In fact, for the first energization, the protective relays may sometimes be temporarily set to give increased sensitivity.

Before any primary equipment is connected into the existing power system, the phasing must be proved. This is to make sure, for example, that the **A**-phase of the bus is connected through the **A**-phase circuit breaker, and disconnects to the **A**- phase of the transmission line. Phases **B** and **C** must be similarly connected. However, visual inspection is not always possible; for example, a three-phase transformer has internal connections. Furthermore, remember that there will be a phase shift between primary and secondary for a **Y/Δ** connection. In most cases, phasing of the transformer would have been tested during installation by applying a low voltage, say, **600-volts**, to the high voltage side and measuring voltages on the secondary. Plotting the resultant phasor diagram will show the voltage ratio, phasing, the phase shift, and phase sequence, see Fig. 2.3-2.

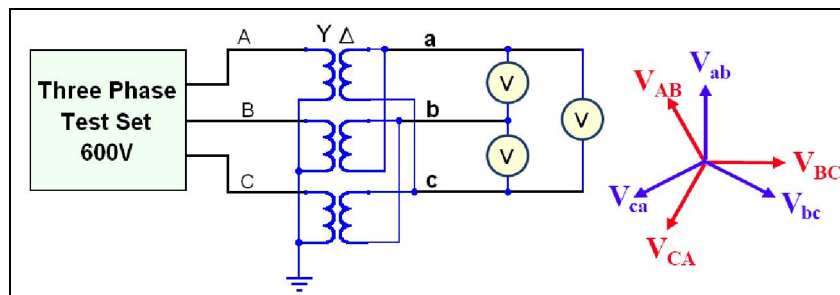


Fig. 2.3-2 Phasing Transformer Connections (Plotting Phasor Diagram)

For voltages up to, say, 25 kV, insulated phasing sticks can be inserted into energized switchgear spouts, or across open disconnects, to check the voltage across the break for each phase. If phasing is correct there should be zero, or nearly zero, voltage across the open contacts. However, if phasing is incorrect, a high voltage will appear across two of the phases.

Let us, look at a specific example of phasing.

- Before paralleling a new generator to an existing bus, we must ensure that phase sequence is identical on both sides. This may be done on the high voltage side of the unit transformer, see Fig. 2.3-3.
- Open the terminal links and back feed the VT's by energizing the unit transformer from the high voltage side. Phasing of the VT's is then compared Fig. 2.3-4. Phasing (compared to the known source) should be identical in both sides of the unit transformer. Remember that there may be a phase shift across the unit transformer, and this will have to be taken into account.

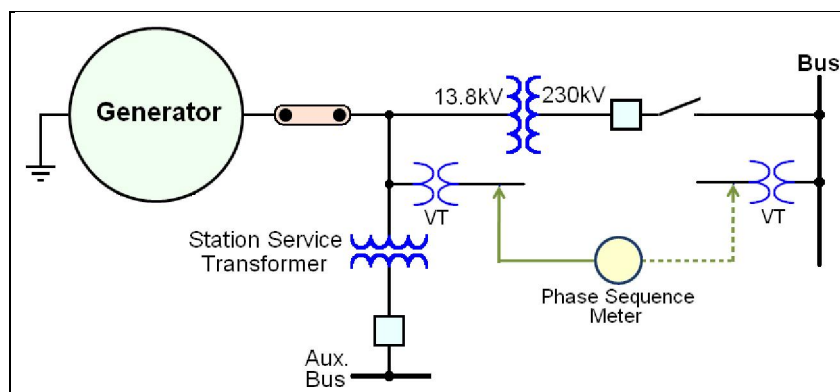


Fig. 2.3-3 Check Phase Sequence on Both Sides of Unit Transformer

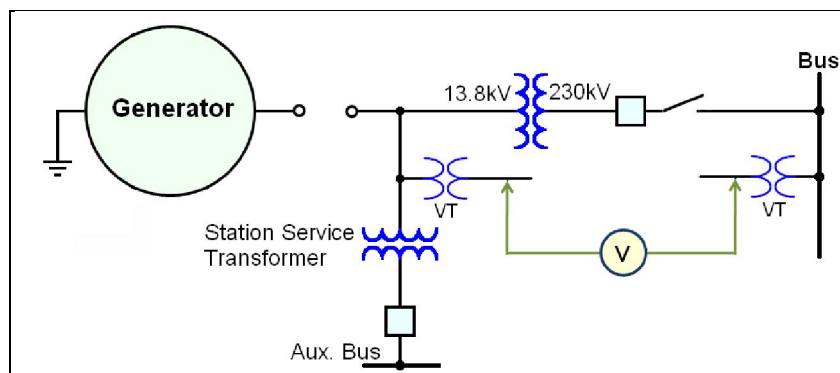


Fig. 2.3-4 Check Phasing on Both Sides of Unit Transformer

It is most important to make sure that the synchroscope is receiving correct information. It must be connected correctly to the VT's on either side as shown in Fig. 2.3-5. Remember that there may be a phase shift across the unit transformer, and this will have to be taken into account by the synchroscope connections. Once the generator is paralleled to the bus, the load on the turbine generator can be raised sufficiently to give adequate current readings on the CT secondary and so allow in-service readings to be taken at the CT links.

SEC procedures will provide comprehensive instructions for initial energization of primary equipment.

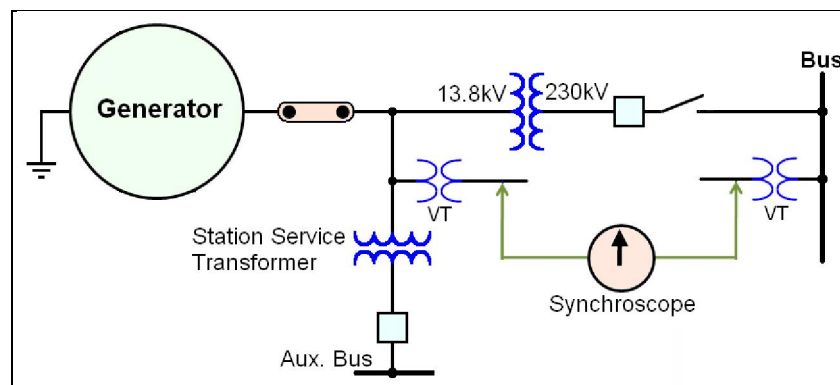


Fig. 2.3-5 Connection of Synchroscope

Fig. 2.3-6 shows an example of in-service readings taken at the relay panel of the generator differential protection. The objective is to test the magnitude and phase angle of current in each of the restraining coils and operating coils. A suitable ammeter and phase angle meter is connected to the circuit under test (through a test plug). The phase angle meter must be provided with a fixed voltage, which can be used as reference in order to determine the phase angle and consequent direction of current.

Transformer differential protection can be checked in a similar manner, but in this case we should expect to see some current passing through the operating coil. This error current (or spill current) is due primarily to the selection of transformer taps plus the effect of dissimilar CT's on either side of the transformer.

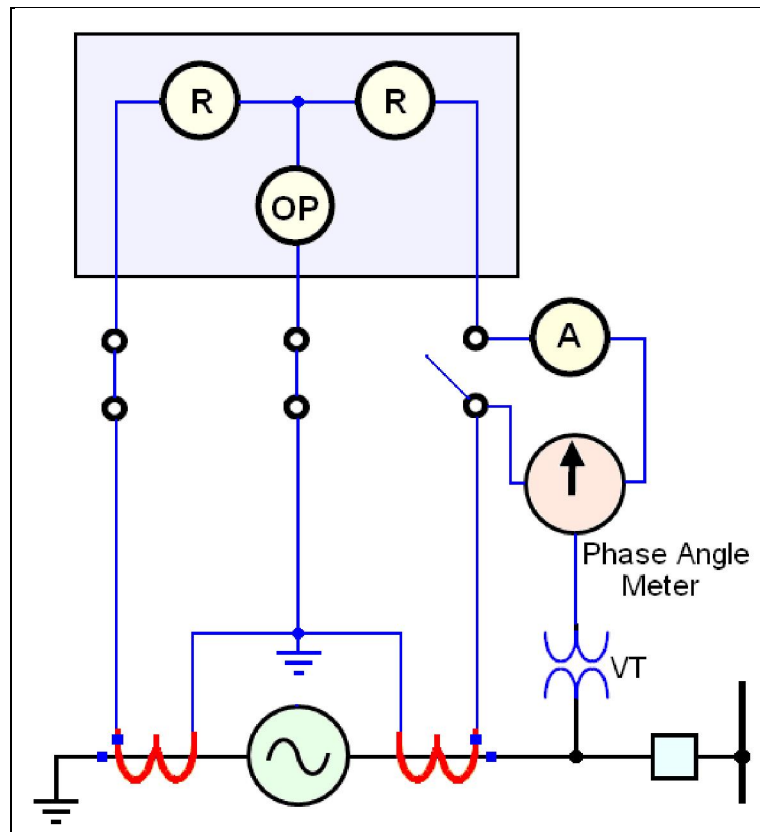


Fig. 2.3-6 In-Service Readings for Generator Differential Protection

As soon as possible, with load on the generator, the corresponding bus protection CT's must be checked for balance and secondary current magnitude and direction. When this test is completed, we should check at the protection relay panel that the total of all the bus CT currents is zero or very close to zero.

When carrying out commissioning tests, remember that you are part of the overall commissioning team. All drawings should be marked up to show the actual as-built condition, including modifications made during the commissioning tests. These must be passed on to the appropriate engineering department.

Also, inform the operators of any changes and any other pertinent information. Good communication and coordination are absolutely vital. More importantly, pay attention to safety procedures at all times.

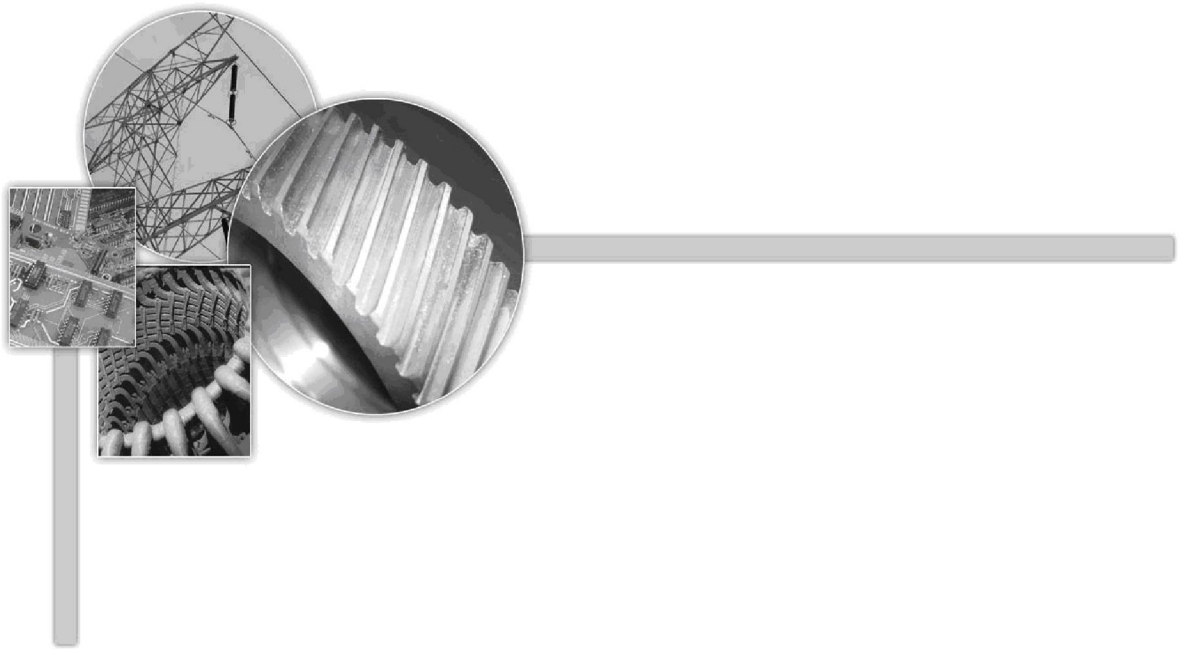
REVIEW EXERCISE

1. Why a relay is usually tested in its own case?
2. List 5 typical tests performed on relays.
3. What is the objective of functional testing of tripping circuits?
4. List 5 items which are not truly part of the protection system but which require functional testing.
5. List 4 tests involved in the commissioning of a power line carrier system.
6. What does “proving” phasing mean?
7. In Fig. 2.3-4, how is phasing proved?
8. What is the objective of the test shown in Fig. 2.3-6?
9. Why would you expect to see more error or spill current when checking transformer differential protection as compared to generator differential protection?

10. When carrying out in-service checks on directional relays the voltage balance and phase sequence of secondary voltages applied to the relay must be checked.
True or False?

11. **Complete the following with the suitable words:**

- a) When performing in-service tests the _____ and _____ should always be in operation to help analyze any incidents.
- b) When using phasing sticks across open disconnect if phasing is correct you should read _____ voltage across the switch on all phases.
- c) Before energizing primary equipment, make sure that all _____ has been completed; that all _____ grounds have been removed; and, that all _____ are cleared.
- d) Before any primary equipment is connected into the existing power system, the phasing must be _____.



UNIT 3

STATIC RELAYS

UNIT-3

STATIC RELAYS

OVERVIEW

This unit discusses the theory and operation of static relays, including the main components of static relay, the basic circuits, the types of power supplies, and the static relay applications.

OBJECTIVES

Upon completion of this unit, the trainee will be able to:

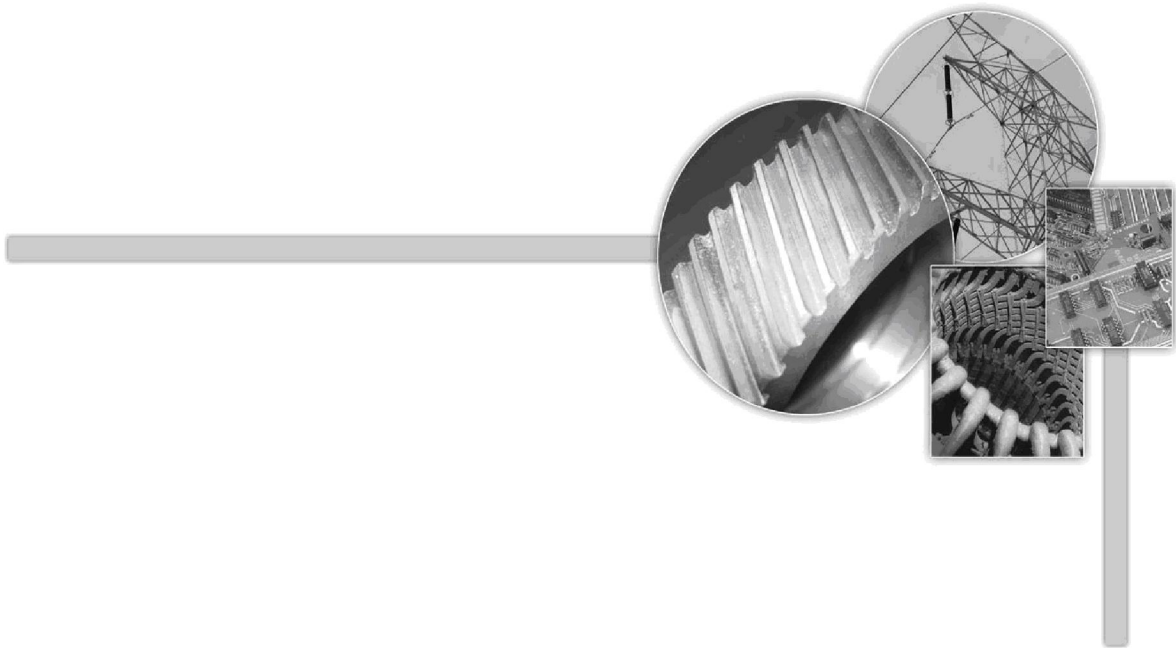
State the advantages and limitations of static relays.

List the main components and control devices of static relays.

Identify the types of power supplies of static relays.

Identify the basic circuits of static relays.

Demonstrate and performing the static relay applications.



LESSON 3.1

SEMICONDUCTOR DEVICES IN STATIC RELAY

LESSON 3.1

SEMICONDUCTOR DEVICES IN STATIC RELAY

OVERVIEW

This lesson discusses the advantages and limitations of static relays. It scopes out the important components of the static relays, including their symbols, constructions, characteristics, and its applications in static relay circuits.

OBJECTIVES

Upon completion of this lesson, the trainee will be able to:

- Identify the advantages and disadvantages of static relays.
- Illustrate the transistor family, used in static relays.
- Demonstrate the thyristor families, used in static relays.
- Demonstrate the applications of static relay components.

INTRODUCTION

Static relays are the generation of the protective relays, next to the electromechanical relays. The target of static protective relay is the same as electromechanical relay to use the input signals (from CTs &/or VTs), converting them into voltage signal; so called actual (measured) values; and compares it with reference values (setting) which acts in a voltage divider circuit through an electronic circuit fed from the relay power supply to close contacts and produce trip signals. The electronic comparator circuits verify the comparison between actual values and reference (setting) values.

Static relay consists of electronic circuits in the form of printed circuit boards (PCB). Each circuit consists of electronic components like diodes, BJT transistors, MOSFETs, SCRs, integrated circuits, logic circuits, operational amplifiers, etc.

ADVANTAGES OF STATIC RELAYS

The static relay offers certain advantages over electromechanical types, these are:

1. Smaller, lighter and sensitive.
2. Consumes less power.
3. Lower burden to the CT's and PT's.
4. It provides the same characteristics as electromechanical relays and more.
5. Low maintenance owing to the absence of the moving parts.
6. Fast operation and Quick reset action.
7. Long life.
8. Not affected by the number of operations.

LIMITATION OF USING STATIC RELAYS

Static relays have certain limitations as compared to their equivalent electromechanical relays. The following is some limitations and disadvantages for static relays:

1. The relay works at low ambient temperature.
2. Voltage spikes can damage the relay.
3. The relay is subjected to interference from power system transients.
4. The relay circuits are subjected to false operation due to external resonance.
5. Static charges can damage the relay components if not properly grounded.

ELECTRONIC COMPONENTS USED IN STATIC RELAY

DIODES

Diode is the most component used in the static relay circuits. It was discussed in last stage (1D-BSP102). It has two terminals anode and cathode. Offering very low resistance when a forward current flows from anode to cathode, and looks very high resistance in the reverse direction. There are many types of diode used in many applications according to its specifications and characteristics.

LIGHT EMITTING DIODE (LED)

Light emitting diode (LED) is two-terminal diode (anode and cathode). When a forward voltage exceeds 0.7V is applied to the LED, it looks bright, when the signal is less than 0.7V or reversed, the LED is dim. LEDs are widely used in static relays. It gives indication for normal operation, fault cases, and type of event. Many colors can be used to Distinguish between events, Fig. 3.1-1.

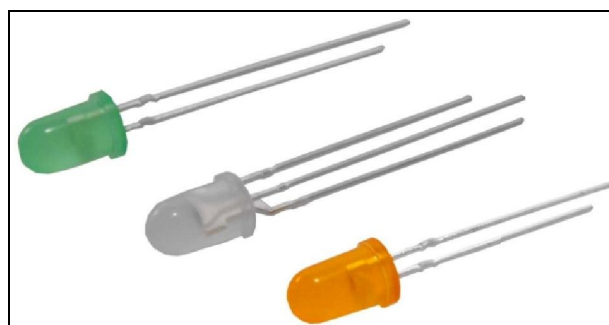


Fig. 3.1-1 Different Colors of Light Emitting Diodes (LEDs)

PHOTO TRANSISTOR & OPT ISOLATORS

Phototransistor is two terminals transistors (collector & emitter). The triggering of phototransistor depends on applying photo light signal then the transistor conducts. The light emitting application is needed when electric isolation and matching between control signal and switching devices is required between two circuits. Phototransistor is widely used in static relays, in input and output through many integrated circuits (ICs) names opto-coupler, Fig. 3.1-2.

Opto-coupler is an IC that contains LED and opto-transistor. When the LED is energized, it produces internally infra red signal that affects the phototransistor base to let it to turn on as a switch, completes the input or output circuit and initiates action. The main advantage is that the input and output circuit are electrically isolated from each other. These keep voltage spikes and other interference out of the output circuit.

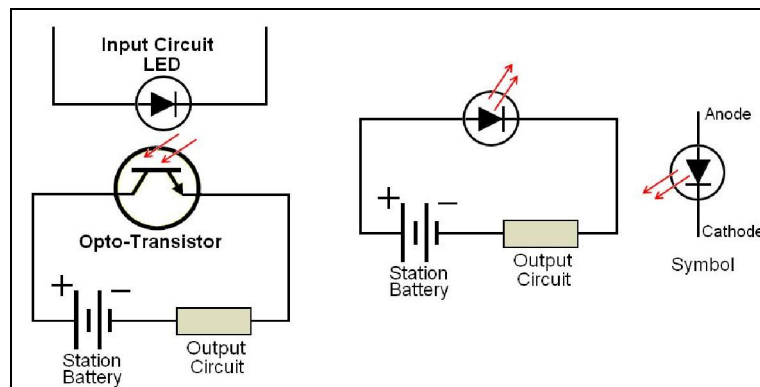


Fig. 3.1-2 Using Phototransistor for Circuit Isolation

There are many types of opto-couplers as shown in Fig. 3.1-3.

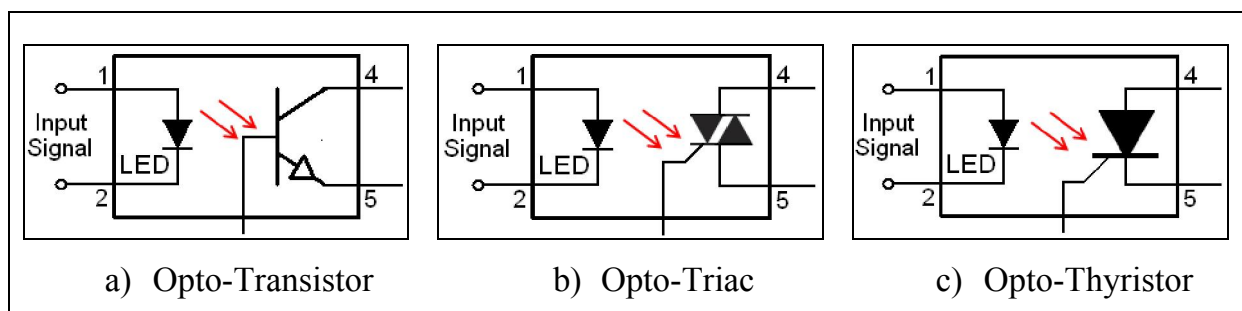


Fig. 3.1-3 Different Types of Opto-coupler

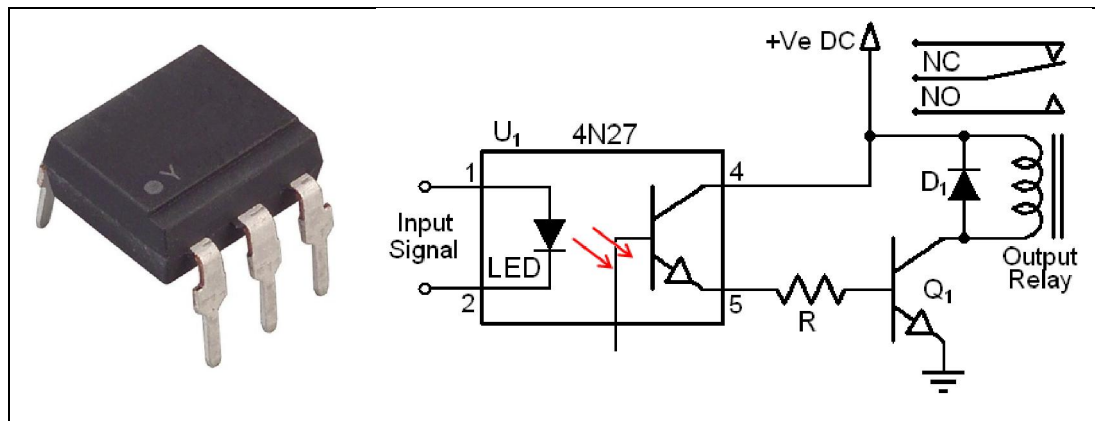


Fig. 3.1-4 Opto-transistor Driving Output Auxiliary Relay

The function of diode D_1 is to protect transistor Q_1 against back emf from relay coil when Q_1 cut-off.

Many types of diodes are used in different applications, as shown in table below:

SIGNAL DIODE

It is widely used as rectifier in most applications of small power circuits.

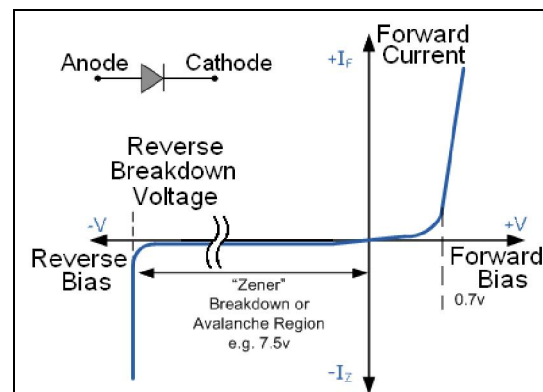


Fig. 3.1-5 Signal Diode Characteristics

FOUR LAYER DIODE

The four-layer diode (Fig. 3.1-6) is used to obtain pulses from a DC current. As the characteristics shows, the forward current, I is small until the voltage reaches a threshold, V_s , at which point the diode conducts.

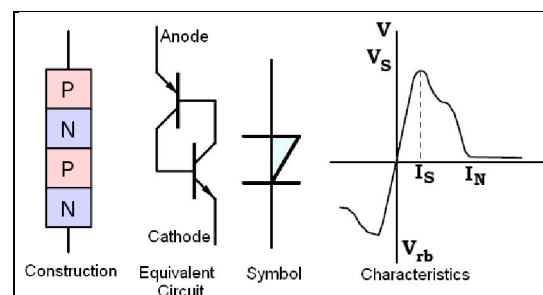


Fig. 3.1-6 Four-Layer Diode Characteristics

Subsequently, the diode continues to pass current with V considerably reduced. It is used in high-speed switching circuits.

ZENER DIODE

Zener diode operates in the reverse direction. When the current flow from cathode to anode, the zener acts to fix the output voltage. Therefore, it is used in DC voltage regulation circuits.

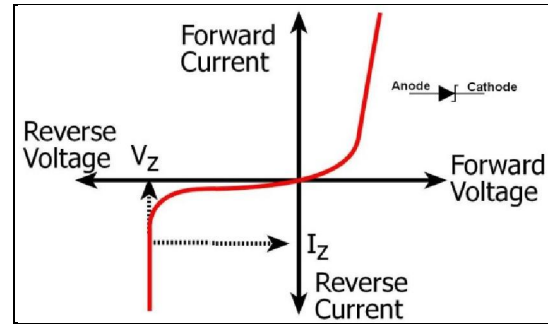


Fig. 3.1-7 Zener Characteristics

VOLT TRAP, THYRECTOR, ZENER CLIPPER

Where surges or transient are oscillating, or for positive and negative peaks, the back-to-back Zener (Fig. 3.1-8) known as Voltage Trap, Zener Clipper diode, or Thyrector diode, provide effective surge suppression.

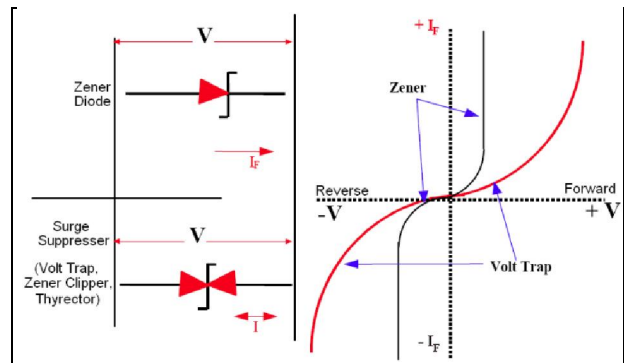


Fig. 3.1-8 Back to Back Zener Characteristics

The characteristics of these diodes are essentially the same in both the foreword and reverse directions.

VARISTOR

A metal oxide varistor (MOV) is a special type of resistor that changes its resistance with rise in voltage, a very high resistance at normal voltage and very low resistance at high voltage (above the trigger voltage). It acts as a switch. It is usually used to protect the next components against surges and voltage spikes.

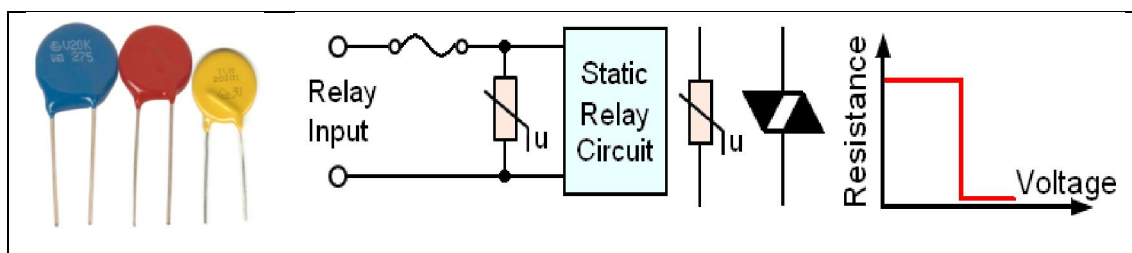


Fig. 3.1-9 Metal Oxide Varistor

THERMISTOR

Thermistor is a temperature-dependent resistor. There are two kinds, classified according to the sign of their temperature coefficients:

Positive Temperature Coefficient (PTC) resistor is a resistor that when the temperature rises the resistance of the PTC increases. It acts as a self-repairing fuse.

Negative Temperature Coefficient (NTC) resistor is a resistor that when the temperature rises the resistance of the PTC drops. It acts as a self-repairing fuse. NTCs are often used in simple temperature detectors and measuring instruments. The thermistor symbol and its characteristics are shown in Fig. 3.1-10.

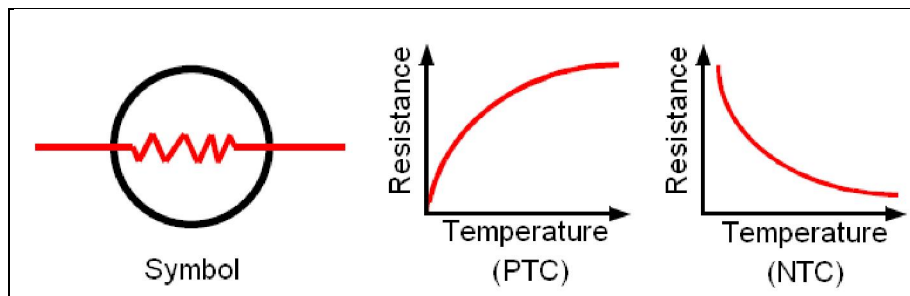


Fig. 3.1-10 Thermistor Symbol and Characteristics

SENSISTOR

Sensistor is a semiconductor-based thermistor with a negative temperature coefficient, useful in compensating for temperature-induced effects in electronic circuits. The sensistor symbol and characteristics are shown in Fig. 3.1-11.

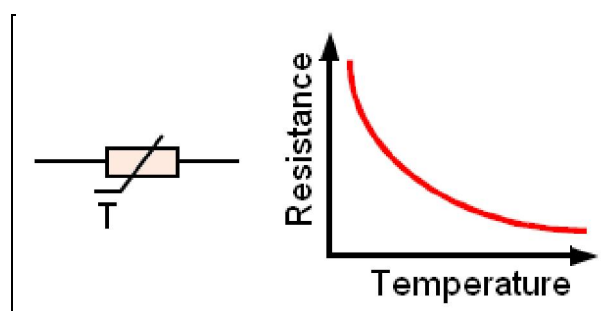


Fig. 3.1-11 Sensistor Symbol and Characteristics

TRANSISTORS

BI-POLAR JUNCTION TRANSISTORS (BJT)

Bi-Polar Junction Transistor (BJT) is three-terminal control device. There are two types PNP and NPN, where the both are widely used in static relay circuits. It is used in amplifier circuits according to the characteristics as shown in Fig. 3.1-12. The amplifier modes always operate in the active region.

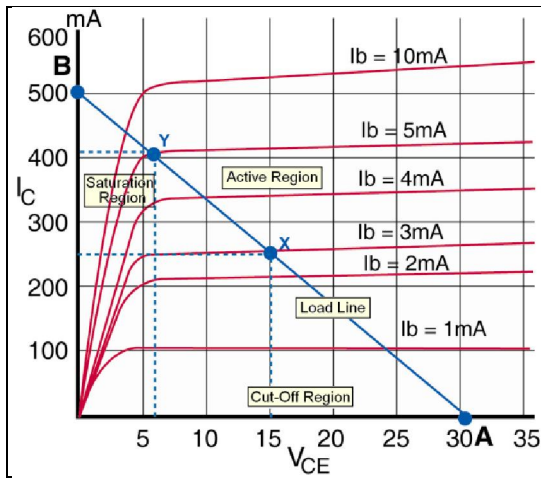


Fig. 3.1-12 Bipolar Transistor Characteristics

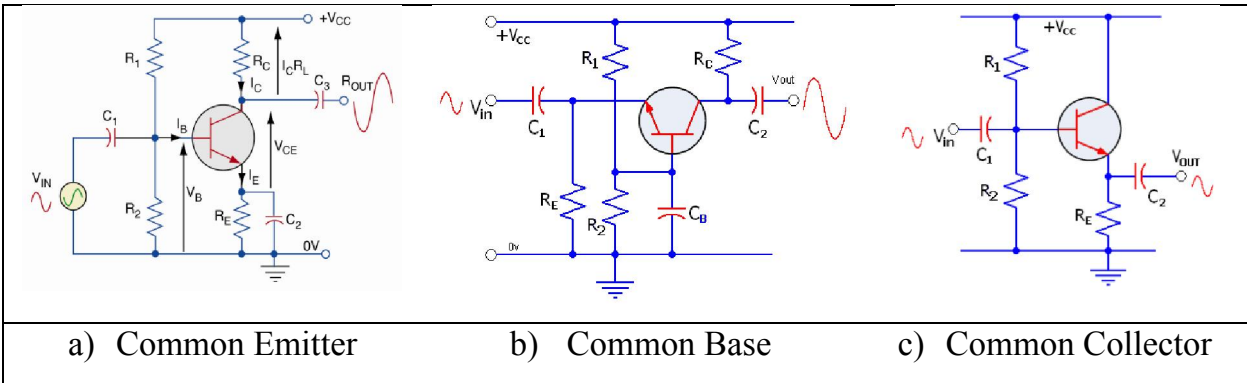


Fig. 3.1-13 Transistor Amplifier Configurations

The common emitter configuration is the best mode to amplify voltage and current, therefore it is called power amplifier. A comparison for the amplifier modes characteristics is shown in the following table 3.1-1.

AMPLIFIER TYPE	COMMON BASE	COMMON EMITTER	COMMON COLLECTOR
Input /Output Phase Relationship	0°	180°	0°
Voltage Gain	High	Medium	Low
Current Gain	Low (α)	Medium (β)	High (γ)
Power Gain	Low	High	Medium
Input Resistance	Low	Medium	High
Output Resistance	High	Medium	Low

Table 3.1-1 Comparison between the Transistor Amplifier Modes

Bipolar transistor as it is used in amplification it is also used in switching the protection output signals to the output devices as shown in Fig. 3.1-14.

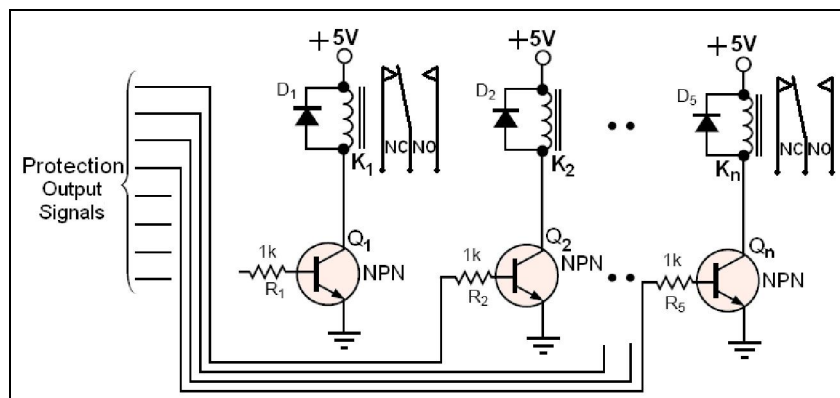


Fig. 3.1-14 Using Transistors for Switching Output Signals

JUNCTION FIELD EFFECT TRANSISTOR (JFET)

JFET is a special type of transistor that widely used in high frequency circuits and high speed switching mode power supplies. It is also used to match cascaded circuit, where the transfer signals are weak and required to upgrade its input impedance. This transistor consists of a piece of high-resistivity semiconductor material (usually silicon) which constitutes a channel for the majority carrier flow. The magnitude of this current is controlled by a voltage applied to a gate, which is a reverse-biased PN-junction formed along the channel, Fig. 3.1-15.

When the JFET junction is reverse-biased, the gate current is practically zero, whereas the base current of the bipolar transistor is always some value greater than zero. The JFET is a high-input resistance device, while the input resistance of the bipolar transistor is relatively low. If the channel is doped with a donor impurity, N-type material is formed and the channel current will consist of electrons. If the channel is doped with an acceptor impurity, P-type material will be formed and the channel current will consist of holes. N-channel devices have greater conductivity than P-channel types, N-channel JFETs are approximately twice as efficient conductors compared to their P-channel counterparts.

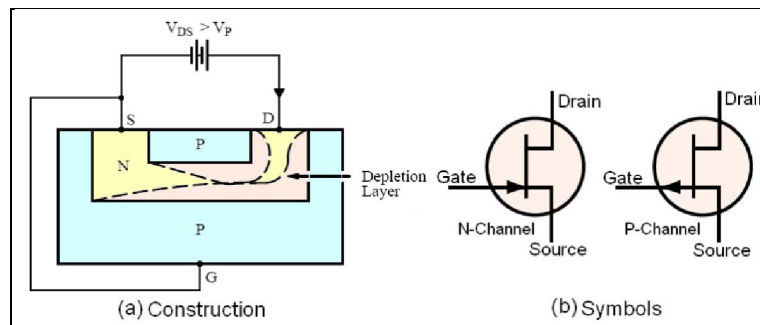


Fig. 3.1-15 JFET Construction and Symbols

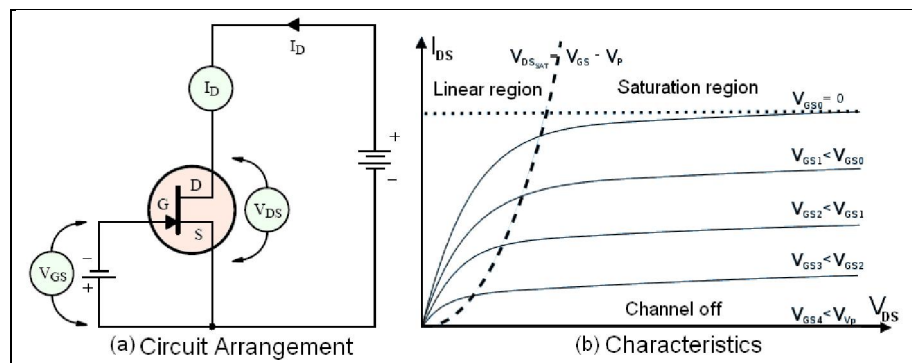


Fig. 3.1-16 JFET Circuit Arrangement and Characteristics

ISOLATED GATE TRANSISTOR (MOSFET)

Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFET) is a transistor used for amplifying or switching electronic signals. In MOSFETs, a voltage on the oxide-insulated gate electrode can induce a conducting channel between the two other contacts called source and drain. The channel can be of n-type or p-type. And

accordingly is called an NMOSFET or a PMOSFET (also commonly NMOS & PMOS). It is by far the most common transistor in both digital and analog circuits.

N-MOS TRANSISTOR

NMOS transistors consist of three terminals: (gate, drain, & source), and body. The source and body are both grounded, a drain current (i_D) will be induced based on voltages applied at the gate (V_{GS}) and drain (V_{DS}) of the transistor.

Every NMOS transistor contains a threshold voltage (V_t) which is constant and unique for each transistor. In order for the transistor to operate, V_{GS} must be greater than V_t . Once this condition has been met, the resulting drain current can be controlled by the voltages supplied at the gate and the drain. The relationship between V_{GS} , V_{DS} , and i_D is described by three regions of operation:

Cut-off Region: there is no channel exists ($i_D = 0$) for all values of V_D . ($V_{GS} < V_t$).

Ohmic/Triode Region: The NMOS transistor is active and not “pinched off.” This means the value of V_{DS} affects the value of i_D ($V_{GS} > V_t$ and $V_{DS} \leq V_{GS} - V_t$).

Active/Saturation Region: The channel is “pinched off” because increases in V_D have no affect on i_D ($V_{GS} > V_t$ and $V_{DS} > V_{GS} - V_t$). In the saturation region, the amount of drain current is directly related to the values of $V_{GS} > V_t$.

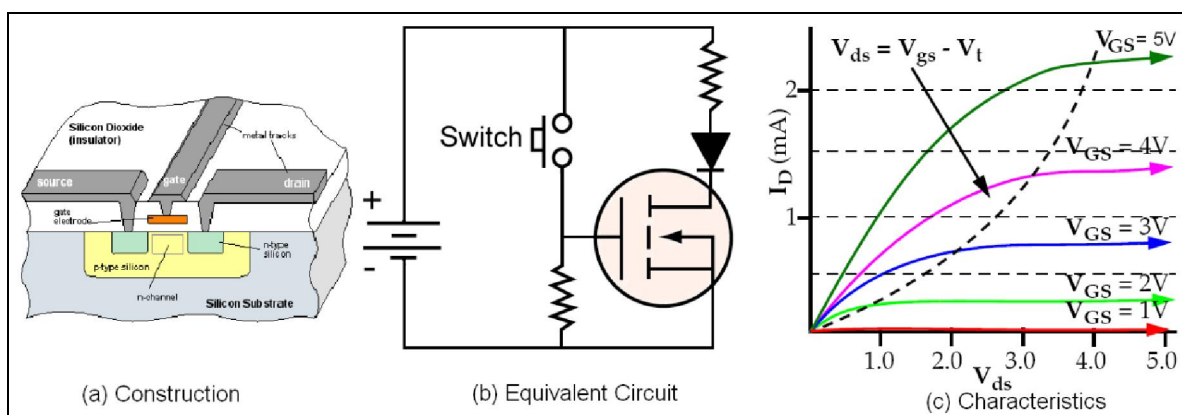


Fig. 3.1-17 Construction & Characteristics of NMOS Transistor

P-MOS TRANSISTOR

In NMOS transistors, the silicon channel between the source and drain is of p-type silicon. When a positive voltage is placed on the gate electrode, it repulses the holes in the p-type material forming a conducting (pseudo n-type) channel and turning the transistor on. A negative voltage turns the transistor off. With a PMOS transistor, the opposite occurs. A positive voltage on the gate turns the transistor off, and a negative voltage turns it on. NMOS transistors switch faster than PMOS, Fig. 3.1-18.

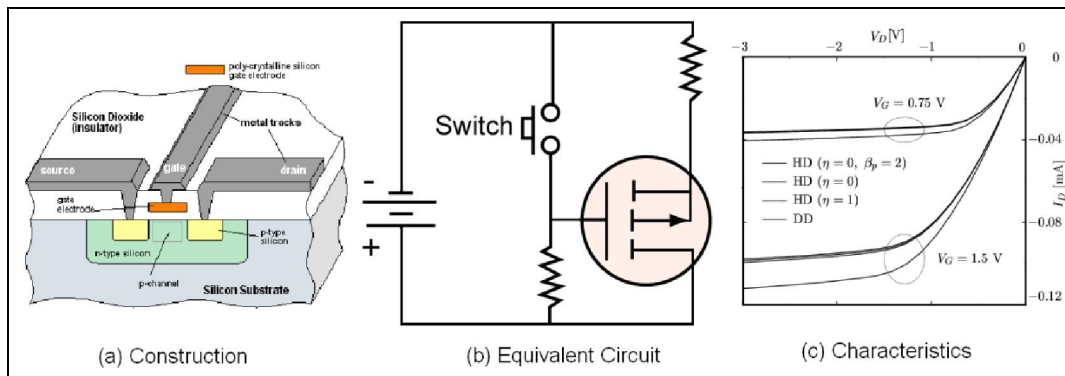


Fig. 3.1-18 Construction & Characteristics of PMOS Transistor

CMOS TRANSISTOR

When an NMOS and PMOS transistor are wired together in a complementary fashion, they become a CMOS (complementary MOS) gate, which causes no power to be used until the transistors switch. CMOS is the most widely used microelectronic design process and is found in almost every electronic product. CMOS, Fig. 3.1-19 offers high noise immunity and low static power consumption.

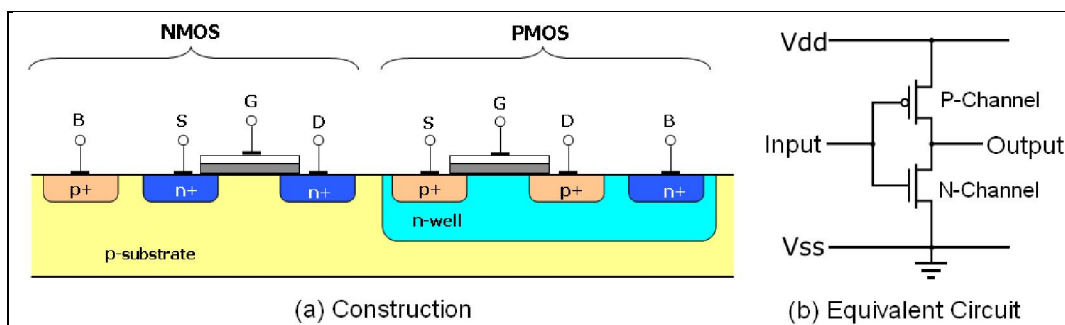


Fig. 3.1-19 Construction & Characteristics of CMOS Transistor

UNI-JUNCTION TRANSISTOR (UJT)

Unit-junction transistor component is commonly used in the oscillators, timing circuit and as a trigger device for SCR. It consists of an N-type semiconductor bar having two electrical connection Base-1 and Base-2, and P-type point on the Emitter. Normally Base-2 is kept constant and positive resistance with respect to the base-1. When V_E reaches the peak value (V_P), the device conducts and passes current I_E . Current will continue to flow as long as (V_E) does not fall below the minimum value (V_V). (See Fig. 3.1-20).

UJT conducts almost at a steady emitter voltage every time and a further increase of emitter voltage drives UJT to saturate with large emitter current.

The negative resistance effect is shown on the emitter characteristic curve. Beyond the valley point on the curve, I_E increase linearly with emitter voltage and the resistance becomes positive again.

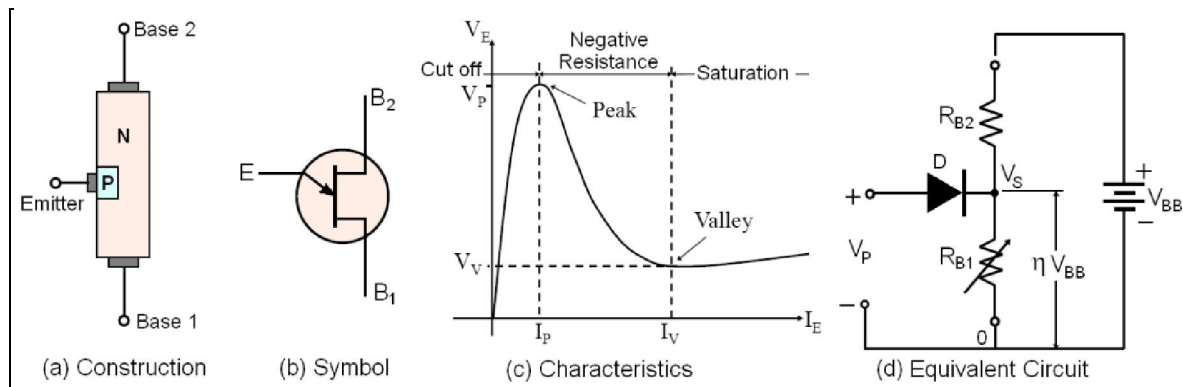


Fig. 3.1-20 UJT Construction and Circuit Arrangement

One of the important parameters of the UJT is the intrinsic standoff ratio, identified by the Greek letter Eta (η), its value is around 0.4 and 0.9 according to its industrial number from data sheet. It affects peak point firing voltage (V_P), which expressed as follows:

$$R_{BB} = R_{B1} + R_{B2}$$

$$\eta = R_{B1} / (R_{B1} + R_{B2}) = R_{B1} / R_{BB}$$

$$V_P = V_D + V_S = 0.7V + I_B R_{B1} = 0.7V + \eta V_{BB}$$

$$V_S = \eta V_{BB}$$

UJT is not used as an amplifier; it is used mainly for timing, triggering, sensing, and waveform generation circuits. They can control accurate time delays, timing pulses, saw tooth waveforms, and square wave transitions.

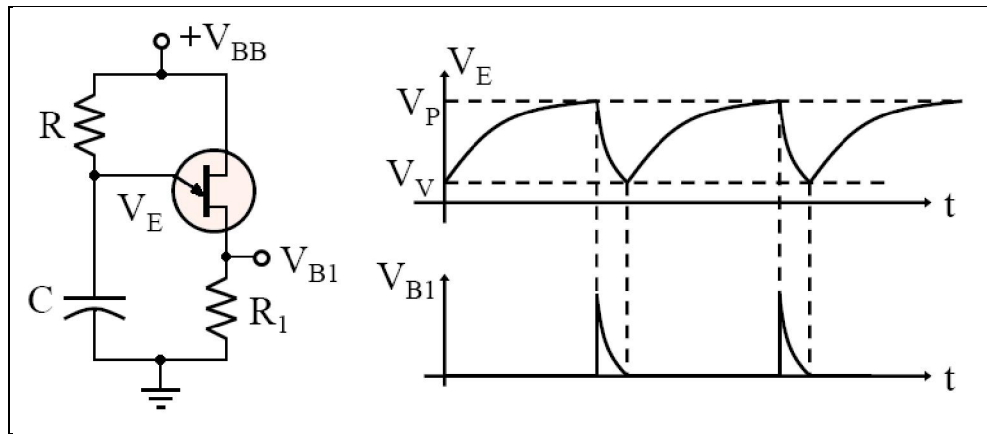


Fig. 3.1-21 Relaxation Oscillator and its Waveform

The simplest application of a UJT is as a relaxation oscillator, which consists of a capacitor (C) is charged gradually through resistor (C) and then discharges rapidly through resistor (R₁) as shown in Fig. 3.1-21. In the oscillator circuit, (R₁) limits the emitter current and provides periodic pulse waveform.

The oscillator frequency is expressed as:

$$f = 1 / (R C \ln (1 / (1 - \eta)))$$

Where (ln) is the logarithm to base (e), where $e = 2.7$

PROGRAMMABLE UNI-JUNCTION TRANSISTOR (PUT)

PUT works as UJT, except that η in the UJT is fixed and given from data sheet of the component. In PUT, η is programmable by the external resistors values R_{B1} and R_{B2}.

Fig. 3.1-22 shows the PUT construction and characteristics. Fig. 3.1-23 shows application of PUT in triggering SCR. In static relay, the load is represented with auxiliary relay coil to make switching.

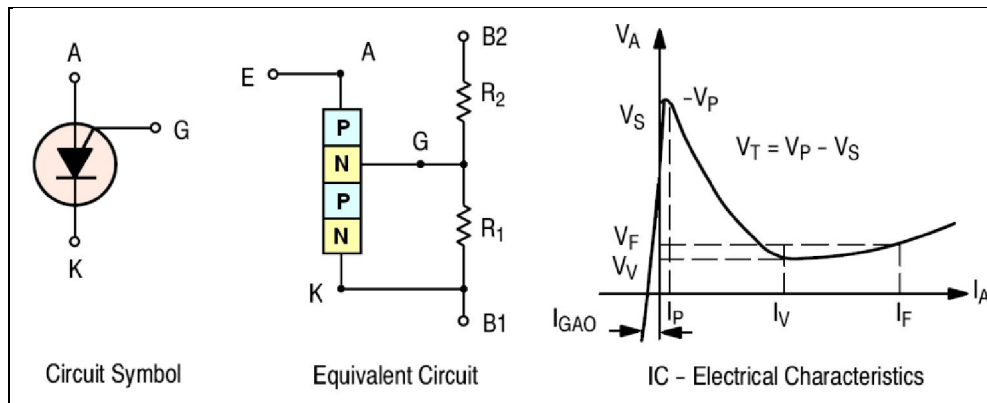


Fig. 3.1-22 PUT Construction and Characteristics

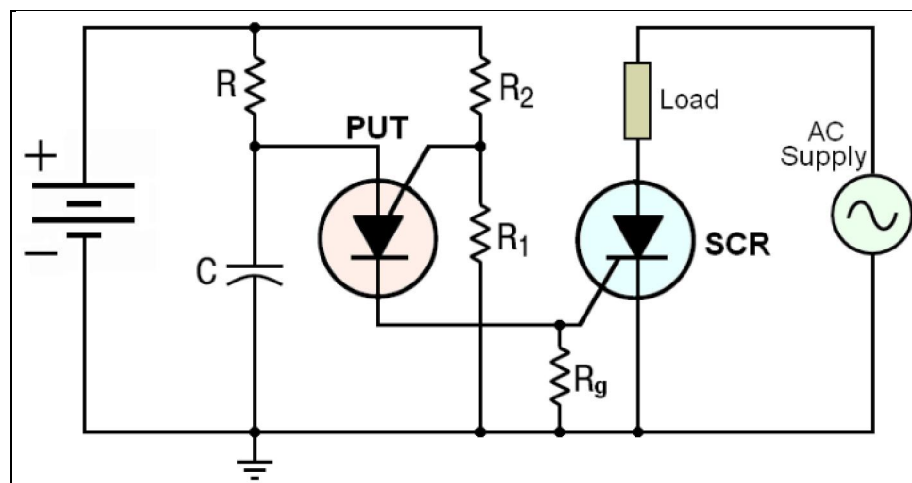


Fig. 3.1-23 Application of PUT for Triggering SCR

SILICON CONTROLLED RECTIFIER (SCR)

SCR (Thyristor) is three terminal voltage controlling device. It operates as a normal diode after it is turned on; the gate to cathode junction is forward biased. After it has been turned on, SCR conducts when the anode to cathode junction is forward biased. SCR will stay on, even if the gate bias is removed, as long as there is a minimum anode current. The minimum anode current required to maintain SCR conduction is called holding current (I_H). SCR turns off when the anode current (I_A) drops below the holding current (I_H). Holding current (I_H) of each SCR is defined from the data sheet, Fig. 3.1-24. SCR exhibits control only on the positive transition of each cycle of the AC source.

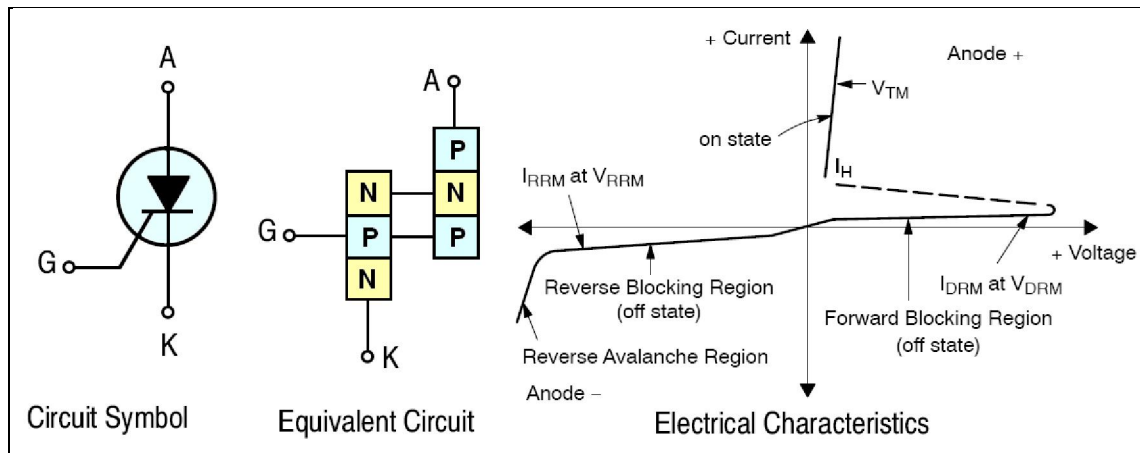


Fig. 3.1-24 SCR Construction and characteristics

A small gate voltage signal can control a large anode to cathode voltage. Therefore, SCR is ideally suited for phase control because of its unidirectional characteristics.

SCRs are used in devices where the control of high power, possibly coupled with high voltage, is demanded. Their operation makes them suitable for use in medium to high-voltage AC power control applications, such as lamp dimming, regulated power supplies, motor control, battery chargers and UPS.

In static relays, SCR is used in switched mode power supplies, DC-to-DC converter, and switching auxiliary output relays.

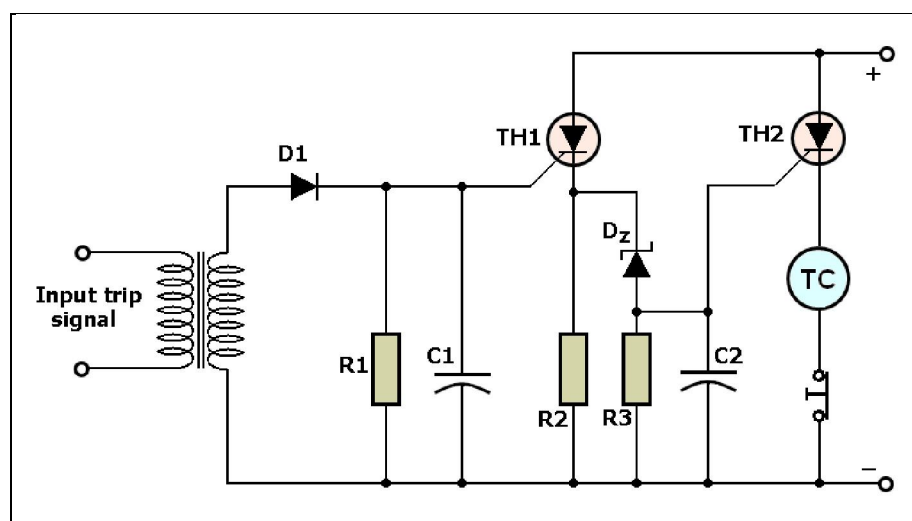


Fig. 3.1-25 Using SCR for Controlling Trip Coil

TRIAC

TRIAC is a three terminals AC semiconductor switch. It operates much like two inverse parallel-connected SCRs. As such, it is capable of conducting with either polarity of terminal voltage gate signal. Thus, it can function as an AC-switch. It consists of a five-layer conductor device having circuit model and characteristic as shown in Fig. 3.1-26.

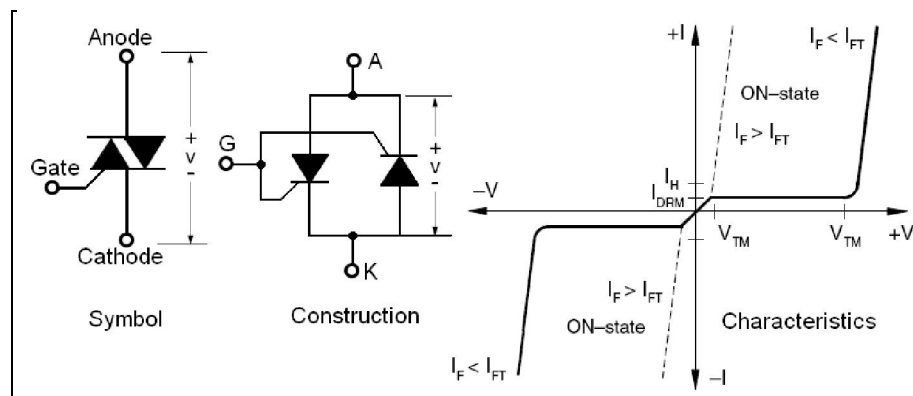


Fig. 3.1-26 TRIAC Construction and characteristics

TRIAC is used sometimes in static relays, especially in the interfacing AC modules and static timers.

DIAC

DIAC is a three-layer diode AC switch used primarily as a triggering device for the TRIAC. It conducts current only at the moment of its break-over voltage has been reached. It operates like two inverse parallel-connected zener diodes.

Once conduction starts, current increases rapidly and voltage across the DIAC decreases. The current pulse produced. Typical application for DIAC for phase control is shown in Fig. 3.1-27.

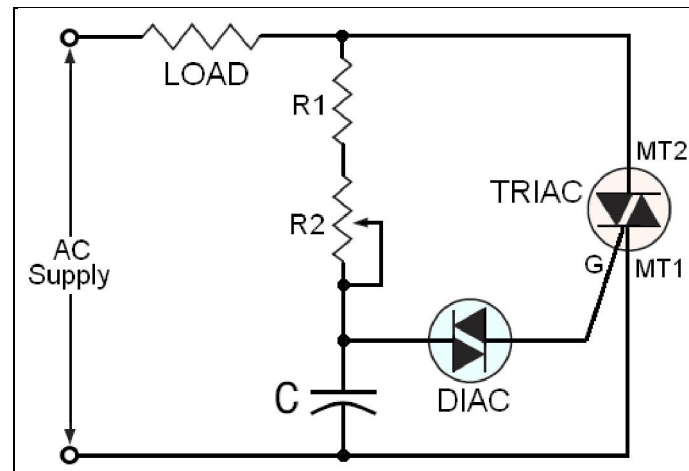


Fig. 3.1-27 Using Triac & Diac for Controlling AC Load

REED RELAYS

A reed relay is a type of relay that uses an electromagnet to control one or more reed switches. The contacts are of magnetic material and the electromagnet acts directly on them without requiring an armature to move them. Sealed in a long, narrow glass tube, the contacts are protected from corrosion, and are usually plated with silver, which has very low resistivity but is objected to corrosion when exposed, rather than corrosion-resistant but more resistive gold as used in the exposed contacts of high quality relays.

Multiple reed switches can be inserted into a single glass tube and actuate simultaneously. As the moving parts are small and lightweight, reed relays can switch much faster than relays with armatures

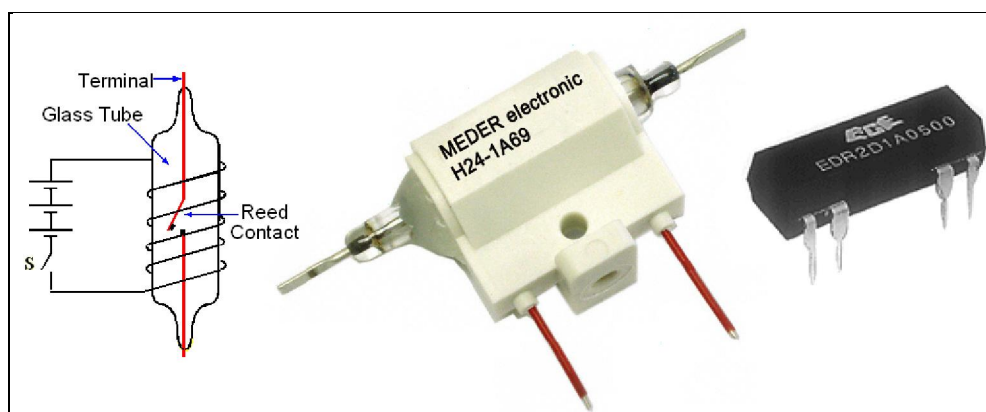


Fig. 3.1-28 Types of Reed Relay

OPERATIONAL AMPLIFIER

Operational amplifier (Op-Amp) is a DC-coupled high-gain electronic voltage amplifier with a differential input and, usually, a single-ended output. Op-Amp produces an output voltage that is typically hundreds of thousands times larger than the voltage difference between its input terminals. Equivalent circuit of ideal Op-Amp is shown in Fig. 3.1-29.

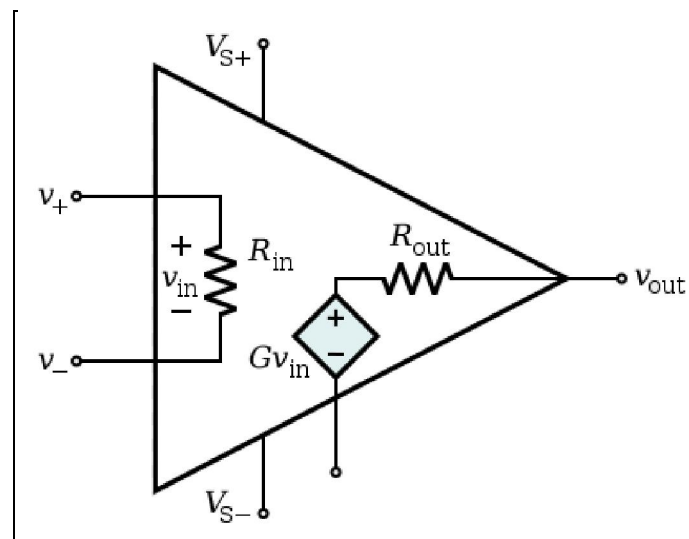


Fig. 3.1-29 Equivalent Circuit of Op-Amp

OP-AMP SPECIFICATIONS

An ideal op-amp is usually considered to have the following properties, and they are considered to hold for all input voltages:

- Infinite open-loop gain (when doing theoretical analysis, a limit may be taken as open loop gain A_{OL} goes to infinity).
- Infinite voltage range available at the output (v_{OUT}) (in practice the voltages available from the output are limited by the supply voltages and the power supply sources are called rails).
- Infinite bandwidth (i.e., the frequency magnitude response is considered to be flat everywhere with zero phase shift).

- Infinite input impedance and zero current flows between its inputs.
- Zero input current (i.e., there is assumed to be no leakage or bias current into the device).
- Zero input offset voltage (i.e., when the input terminals are shorted so that, the output is a virtual ground or $V_{OUT} = 0$).
- Infinite slew rate (i.e., the rate of change of the output voltage is unbounded) and power bandwidth (full output voltage and current available at all frequencies).
- Zero output impedance (i.e., $R_{out} = 0$, so that output voltage does not vary with output current).
- Zero noise.
- Infinite Common-mode rejection ratio (CMRR).
- Infinite Power supply rejection ratio for both power supply rails.

COMMON MODE REJECTION RATIO (CMRR)

A perfect operational amplifier amplifies only the voltage difference between its two inputs, completely rejecting all voltages that are common to both. However, the differential input stage of an operational amplifier is never perfect, leading to the amplification of these identical voltages to some degree. The standard measure of this defect is called the common-mode rejection ratio (denoted CMRR). Minimization of common mode gain is usually important in non-inverting amplifiers.

OP-AMP FOR STATIC RELAYS

Op-Amp acts as a comparison circuit to compare the actual input value (comes from CTs &/or VTs) with the reference (setting) value by adjusting certain resistance on one of the two input terminals.

Op-Amp IC can include up to four Op-Amps per chip, and they can work individually. A dual DC power supply is recommended to feed the Op-Amp chip. The op-amp is used in the static relay to verify most of the required circuit processing from receiving the input signals, which come from CTs and VTs applying the required operations

until it makes the decision if relay trip will be produced or not. The symbol and the integrated circuit package of operational amplifier are shown in Fig 3.1-30.

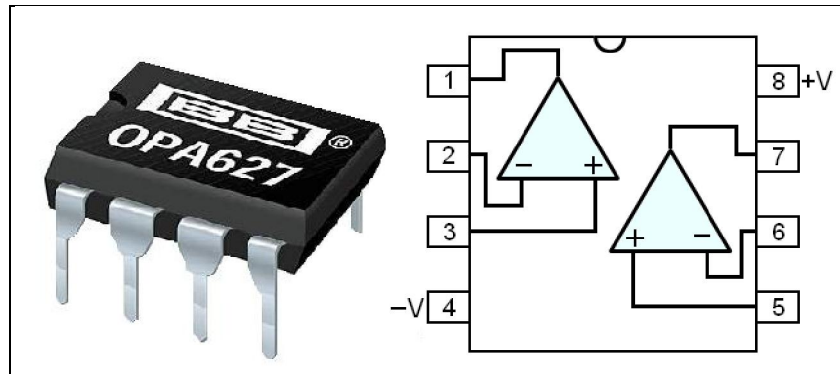


Fig. 3.1-30 Operational Amplifier Pin out and dual Op-Amp IC Configuration

OPERATIONAL AMPLIFIER BASIC CIRCUIT

- Inverting amplifier.
- Summing amplifier.
- Comparator.
- Integrator.
- Non-inverting amplifier.
- Difference amplifier.
- Voltage follower.
- Differentiator.

INVERTING AMPLIFIER

In this circuit, the input signal is inverted and amplified according to the amplification value required limited by the power supply voltage, the input resistance R_{IN} and feedback resistance R_F as shown in Fig. 3.1-31.

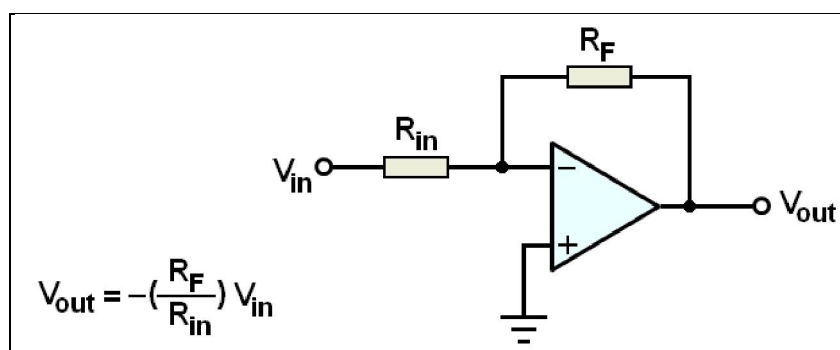


Fig. 3.1-31 Op-Amp as Inverting Amplifier

Inverting amplifier is widely used in static relays. Especially when the actual value (voltage or current) is small and close to the setting value.

NON-INVERTING AMPLIFIER

In this circuit, the input signal is amplified without opposition according to the amplification value, which limited with the power supply voltage, the input resistance R_{IN} and feedback resistance R_F as shown in Fig. 3.1-32.

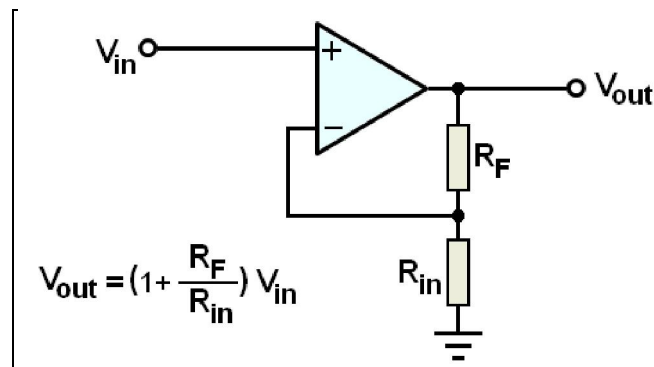


Fig. 3.1-32 Op-Amp as Non-inverting Amplifier

Non-inverting amplifier is used in static relays, where the signal needs to be amplified with small matching resistance to the next stage.

SUMMING AMPLIFIER

In this circuit, many input signals are added instantaneously, and then amplified with opposition according to the amplification value, which limited with the power supply voltage, the input resistance R_{IN} and feedback resistance R_F as shown in Fig. 3.1-33.

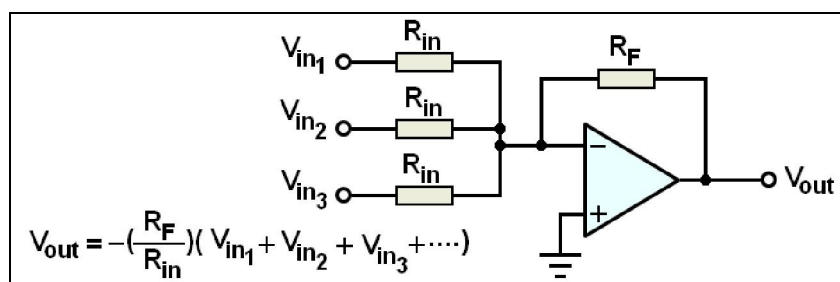


Fig. 3.1-33 Op-Amp as Summing Amplifier

Summing amplifier is used in static relay, where it is required to add instantaneous value for three phase signals to produce zero value. Except at the fault or reversing for any phase the output signal changes to high value to produce trip signal.

VOLTAGE FOLLOWER (BUFFER)

In this circuit, the input signal is produced from the output without amplification and with zero phase shift. However, the output is produced with infinite input impedance and zero output impedance as shown in Fig. 3.1-34.

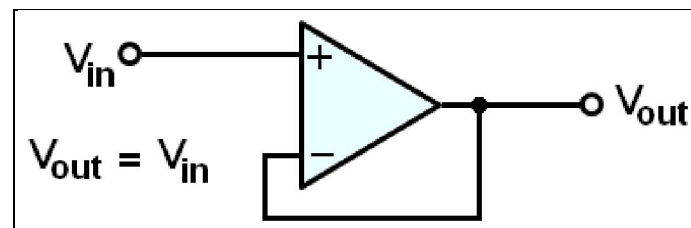


Fig. 3.1-34 Op-Amp as Voltage Follower

The buffer is needed where the signal in some stages of static relay has been attenuated in the cascaded operations due to the difference in matching impedance.

DIFFERENCE AMPLIFIER (SUBTRACTION)

In this circuit, the output signal is produced by amplifying the difference between two input signals, as shown in Fig. 3.1-35.

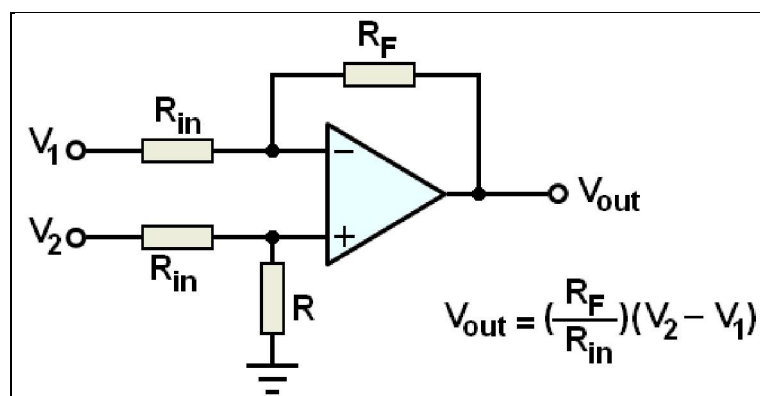


Fig. 3.1-35 Op-Amp as Difference Amplifier

Difference amplifier is used in static relay, where the difference between actual and reference value leads to operating condition.

SIGNAL COMPARATOR

In this circuit, the output is produced absolutely as square wave for any input signal higher than zero and in phase with the input signal, Fig. 3.1-36.

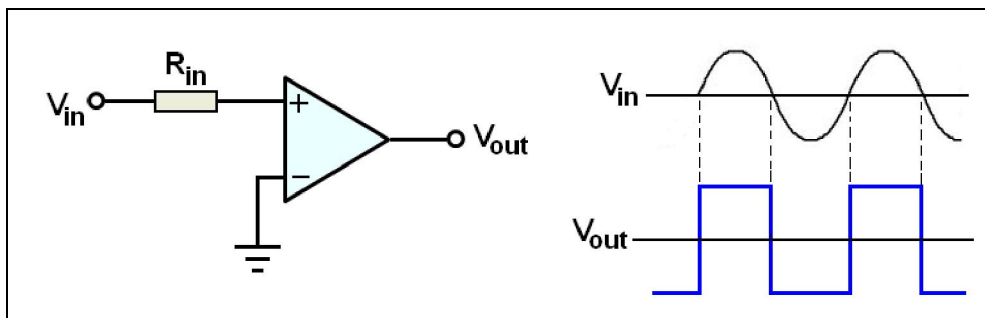


Fig. 3.1-36 Op-Amp as Voltage Comparator

A simple comparator is used in static relay to indicate the instants of the signal when passing through zero crossing, which indicates signal polarity.

INTEGRATOR

In this circuit, the input signal is integrated to produce the output signal, Fig. 3.1-37.

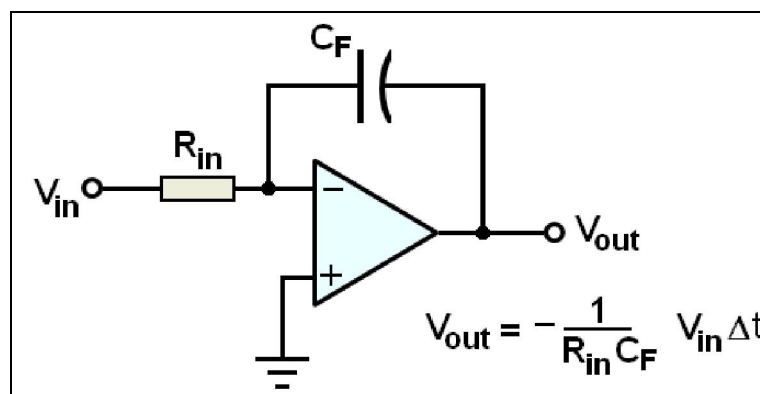


Fig. 3.1-37 Op-Amp as Integrator

DIFFERENTIATOR

In this circuit, the input signal is differentiated to produce output, Fig. 3.1-38.

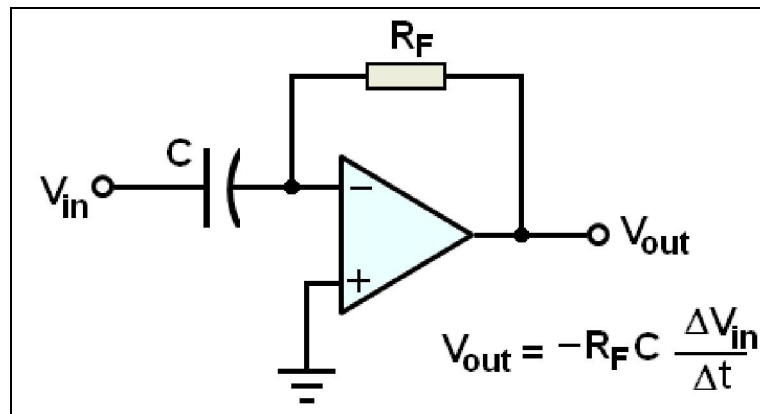


Fig. 3.1-38 Op-Amp as Differentiator

LOGIC GATES

Logic gates are widely used in static relay to determine certain decision depending on one or more given logic information. Those conditions are related to some matter according to the signal levels. Logic gates are combination of some transistors having one or more inputs and have only one output. They are represented in IC form (integrated circuit). Each IC can contain many logic gates to work individually. The likely logic operating functions of the logic gates are AND, NAND, OR, NOR, EX-OR, EX-NOR and NOT operation. Fig 3.1-39 shows the integrated circuit ship of the logic gate IC and pin configuration for quad NAND gates per chip.

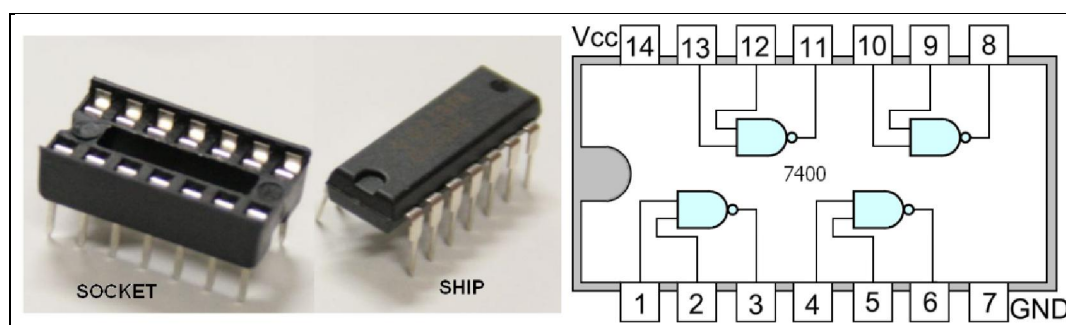


Fig. 3.1-39 Logic Gate IC and pin configuration

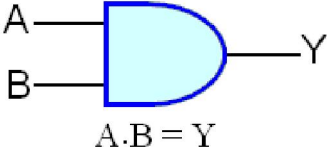
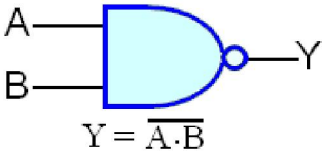
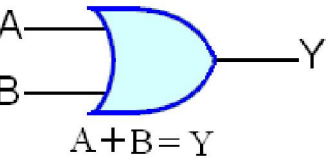
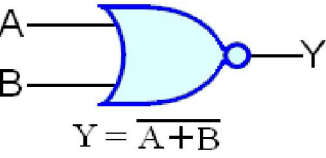
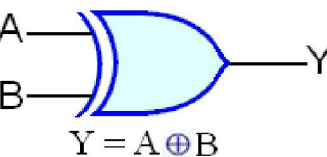
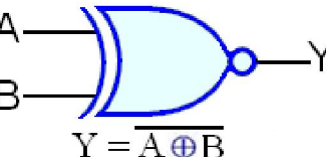
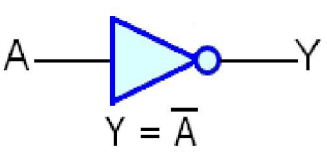
AND Gate	 $A.B = Y$	NAND Gate	 $Y = \overline{A.B}$
OR Gate	 $A+B = Y$	NOR Gate	 $Y = \overline{A+B}$
EX-OR Gate	 $Y = A \oplus B$	EX-NOR Gate	 $Y = \overline{A \oplus B}$
NOT Gate	 $Y = \overline{A}$		

Fig. 3.1-40 Symbols for different types of Logic Gates

The logic gates are related to two families: TTL (Transistor-to-Transistor Logic) and CMOS (Complementary Metal Oxide Semiconductor) known with certain industrial numbers and data sheets. Each logic gate works through truth table to control its input and the output. It must also be powered from a regulated power supply to determine the level of its pin terminal voltage. Fig. 3.1-40 shows the symbols of different logic gates.

Fig. 3.1-41 shows simple logic diagram for directional overcurrent static relay.

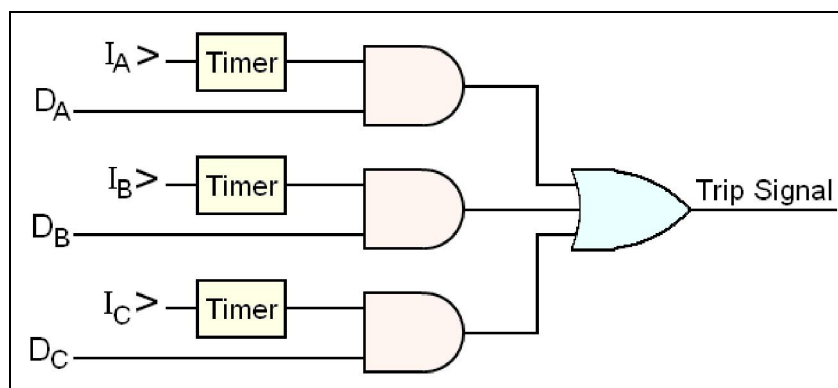


Fig. 3.1-41 Application of Logic Gates in Directional O/C Relay

SUMMARY

- The static relays have certain advantages over electromechanical relays; it is sensitive, smaller, lighter, of less power consumption, fast operation, low burden and less maintenance.
- The limitations of static relays are represented in voltage spikes, static charges, the need to low ambient temperature, and false operation due to external resonance.
- Static relay consists of discrete components and integrated circuits (ICs), which form the basic relay circuits.

Signal diode:	<ul style="list-style-type: none">• It is used for general applications in small power circuits.
Zener diode:	<ul style="list-style-type: none">• It is biased in reverse direction and used in DC circuit protection and applications of voltage regulation.
Thermistor:	<ul style="list-style-type: none">• Temperature dependant resistor having two types: Positive temperature coefficient, resistance increases with increase in temperature. Negative temperature coefficient, resistance decreases with increase in temperature.
Sensistor:	<ul style="list-style-type: none">• A semiconductor-based resistor having negative temperature coefficient.
Light-emitting diode:	<ul style="list-style-type: none">• Used to indicate events.
Photo diode:	<ul style="list-style-type: none">• Used in lighting applications.
BJT transistor::	<ul style="list-style-type: none">• Used in amplifiers and switching circuit applications.
Power diode:	<ul style="list-style-type: none">• Used in power drives and high current load applications.
Opto-coupler:	<ul style="list-style-type: none">• Used to isolate and match very low signal circuit with high power circuit.
Varistor:	<ul style="list-style-type: none">• It protects the relay sensitive components against surges and voltage spikes.

- | | |
|------------------------|--|
| MOSFET: | <ul style="list-style-type: none">• Used in switched mode power supplies, and high frequency devices. |
| UJT: | <ul style="list-style-type: none">• Used for timing, triggering, sensing, and waveform generation circuits. |
| PUT: | <ul style="list-style-type: none">• The same operation as UJT, except that η is programmed by external resistors. |
| SCR: | <ul style="list-style-type: none">• Used in switched mode power supplies, DC-to-DC converter, and switching auxiliary output relays. |
| TRIAC: | <ul style="list-style-type: none">• Used for interfacing AC modules and static timers. |
| DIAC: | <ul style="list-style-type: none">• Used for triggering Triac. |
| Reed relay: | <ul style="list-style-type: none">• Used as high-speed auxiliary relay. |
| Operational amplifier: | <ul style="list-style-type: none">• Used in most static relay functions like summation, subtraction, comparator, integrator, differentiator, and buffer. |
| Logic gates: | <ul style="list-style-type: none">• Used for determining certain decision depending on one or more given logic information. |

REVIEW EXERCISE

Answer the following questions:

1- What is the function of Zener diode?

.....
.....

2- What is the function of varistor?

.....
.....

3- State three functions of operational amplifier in the static relays.

.....
.....

4- What are the advantages of static relays over the electromagnetic relays?

.....
.....

5- Op-Amp is used in static relay as:

- | | |
|---------------|----------------|
| a- Rectifier. | b- Comparator. |
| c- Regulator. | d- Storage. |

6- What is the effect of static relays on the instrument transformer burden?

.....
.....

7- What is the main purpose of opto-coupler?

.....
.....

8- What are the advantages of MOSFET over the BJT?

.....
.....

TASK 3.1-1

UNI-JUNCTION TRANSISTOR (UJT)

OBJECTIVES

Upon completion of this task, the trainee will be able to:

- Demonstrate the operation of a uni-junction transistor.
- Measure some of the characteristics of UJTs.
- Demonstrate a practical application for the UJT.

DISCUSSION

In the first part of this experiment, you will determine the peak voltage (V_P) and valley voltage (V_V) values for a typical UJT, and you will use the V_P value that you obtained to determine the UJT's intrinsic standoff ratio (η). In the second part of this experiment, you will demonstrate the operation of a UJT as a relaxation oscillator.

TOOLS, MATERIALS & REQUIREMENTS

- Heathkit Electronic Design Experimenter (ET-3100)
- Voltmeter
- 1- uni-junction transistor (417-183)
- 1- 47 ohm, $\frac{1}{2}$ watt resistor (yellow-violet-black)
- 1- 100 ohm, $\frac{1}{2}$ watt resistor (brown-black-brown)
- 1- 1 k ohm, $\frac{1}{2}$ watt resistor (brown-black-red)
- 1- 10 k ohm, $\frac{1}{2}$ watt resistor (brown-black-orange)
- 1- 330 k ohm, $\frac{1}{2}$ watt resistor (orange-orange-yellow)
- 1- 10 μ F electrolytic capacitor (25-880)

PROCEDURE

1. Plug in your Electronic Design Experimenter but be sure that the unit is turned off.
2. Construct the circuit shown in Fig. (1-1a). the leads on the UJT (417-183) are identified in Fig. (1-1b). Turn the positive (+) voltage control fully counterclockwise and then turn the $1\text{k}\Omega$ ohm potentiometer (designated R_1) fully counterclockwise.

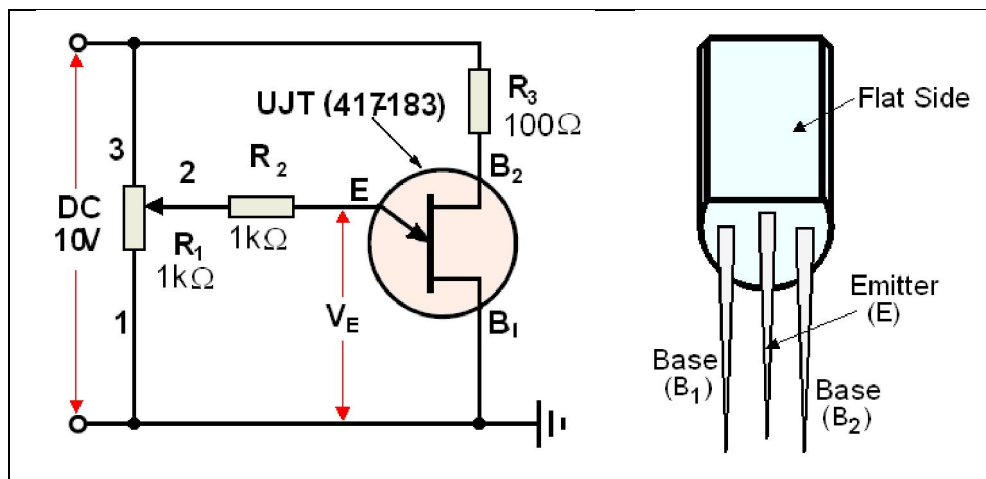


Fig. 1-1 UJT Experimental Circuit

3. Turn ON your Electronic Design Experimenter and adjust the positive (+) voltage controls until +10 volts DC is applied to potentiometer R_1 (measure this voltage across terminals-1 and 3 of R_1). Potentiometer R_1 can be used to control the UJT's emitter-to-base-1 input voltage (V_E) with R_2 serving as the series emitter resistor. Resistor R_3 is used to prevent the base-to-base-2 current from exceeding a safe value and without significantly affecting the normal operation of the circuit.
4. Connect the leads of your voltmeter between the UJT's emitter and base-1 terminals and measure the input voltage (V_E). Gradually turn R_1 clockwise as you observe your meter. Continue to turn R_1 until V_E reaches a peak value and decreases. Note the peak or maximum V_E value that you obtained. This maximum value of V_E represents the UJT's peak voltage (V_P). Since V_E drops suddenly after the V_P value is reached you may fail to detect the peak value the

first time you perform this step. If that is the case, turn the R_1 fully counterclockwise and start again. Record the V_P value that you obtained in the space provided below.

$$V_P = \underline{\hspace{2cm}}$$

5. Continue to observe voltage V_E as you rotate R_1 fully clockwise. Notice that once the V_P value is exceeded, voltage V_E rapidly drops to a low value and then increases by only a small amount. You will find that it is necessary to observe V_E very closely to detect this slight increase. The V_E value that you are observing (with R_1 fully clockwise) is approximately equal to the UJT's valley voltage (V_V). Record this V_V value in the space provided below.

$$V_V = \underline{\hspace{2cm}}$$

6. Use the V_P value that you obtained in step-4 to determine the UJT's intrinsic standoff ratio (η). You will use the equation $V_P = \eta (V_{BB}) + V_F$, which can be rearranged to show the intrinsic, standoff ratio: $\eta = (V_P - 0.7V) / V_{BB}$. When using this equation remember that V_F is the forward voltage drop across the UJT's internal PN-junction or approximately 0.7 volts and that V_{BB} is the voltage source, which is 10 volts. Record your calculated value of η in the space provided below.

$$\eta = \underline{\hspace{2cm}}$$

7. Turn R_1 fully counterclockwise. Then adjust the positive (+) voltage control until +5 volts is applied to R_1 . Measure the voltage between terminals 1 and 3 of R_1 with your voltmeter.
8. Repeat steps-4 & 5 but record the V_P and V_V values that you obtain in the spaces provided below:

$$V_P = \underline{\hspace{2cm}}$$

$$V_V = \underline{\hspace{2cm}}$$

9. Recalculate the UJT's intrinsic standoff ratio using the V_P value obtained in step-8 and the new V_{BB} value of 5 volts. Use the same equation that you used in step-6 and record your results below.

$$\eta = \underline{\hspace{2cm}}$$

10. Turn **OFF** your Electronic Design Experimenter.

11. Compare the calculated value of η of step 8 with the calculated value of step 6.
12. You should found the same result.
13. The calculated value of η should agree with that found in the data sheet of the proposed UJT.

14. Construct the relaxation oscillator circuit shown in Fig. 1-2. Carefully, connect the UJT's leads as shown. Also, be sure to connect the positive end of the $10\ \mu\text{F}$ electrolytic capacitor to the UJT's emitter lead as shown.

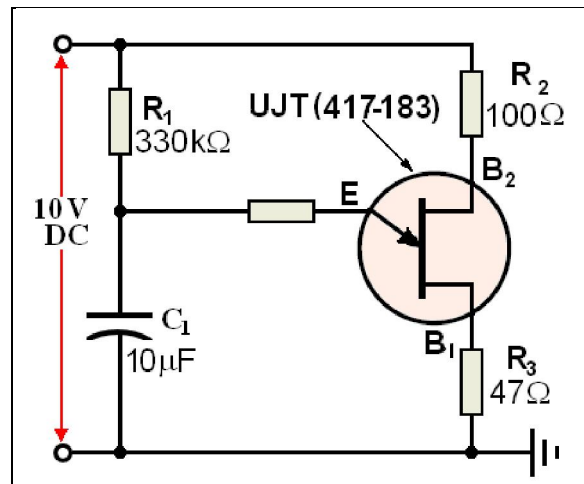


Fig. 1-2 UJT Relaxation Oscillator Circuit

The resistor R_1 has a fixed value and cannot be used to adjust the frequency of the circuit. The frequency is fixed at a very low value so that one complete saw-tooth or pulse waveform is produced approximately every 5 seconds.

15. Turn ON your Electronic Design Experimenter and adjust the positive (+) voltage control until +10V is applied to the circuit (measure with your voltmeter).
16. Measure the voltage across C_1 with your Oscilloscope. This voltage will gradually rise to a maximum value and then rapidly drop to a minimum value to produce a saw-tooth waveform as shown in Fig. 1-3a. Note the maximum and minimum voltages and record them below.

Maximum Voltage = _____

Minimum voltage = _____

Frequency = _____

17. Measure the voltage across R_3 with your voltmeter (use the lowest voltage range). This voltage will occur in pulses as shown in Fig. 1-3b. Observe this voltage for at least 10 to 15 seconds so that you will see at least two voltage fluctuations.

Fig. 1-3 shows UJT relaxation oscillator waveforms with respect to ground at the emitter and b1 terminals.

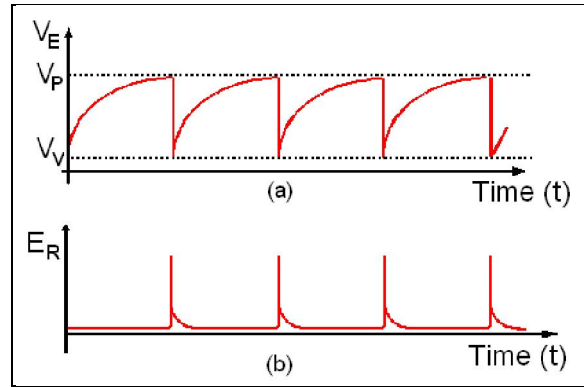


Fig. 1-3 Waveforms

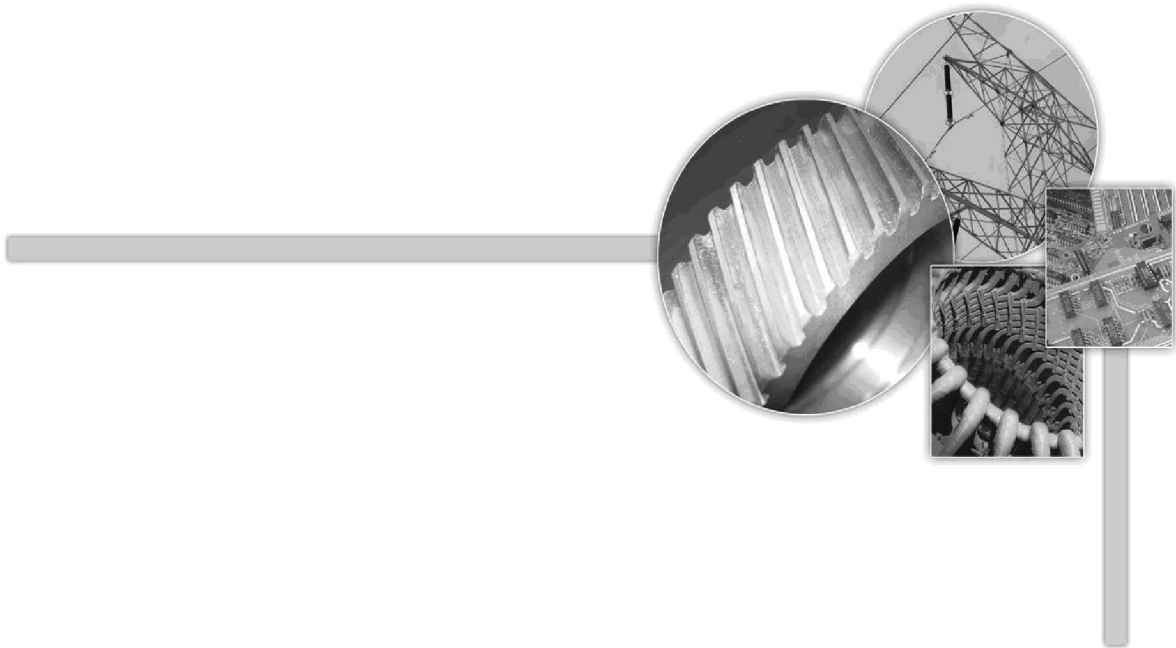
18. Turn OFF your Electronic Design Experimenter. Remove the 330 k Ω resistor (R_1) and install a 10 k Ω resistor in its place. Then turn ON your Electronic Design Experimenter.
19. Measure the voltage across C_1 again with your oscilloscope. Observe the maximum and minimum voltage values and note the frequency of the voltage fluctuations. Record the maximum and minimum values below and indicate if the frequency is higher or lower than it was in step 13.

Maximum Voltage = _____

Minimum Voltage = _____

Frequency is = _____

20. Turn **OFF** your Electronic Design Experimenter.



LESSON 3.2

BASIC CIRCUITS OF STATIC RELAYS

LESSON 3.2

BASIC CIRCUITS OF STATIC RELAYS

OVERVIEW

This lesson describes the basic structure circuits of static relay, including the types of power supply, input circuits, and output circuits for trip the trip signals. The lesson also scopes out the basic internal circuits such as level detector, comparator, timer circuits, phase shift, and polarity detector.

OBJECTIVES

- Identify the major basic circuits included in the static relays.
- Identify the types of power supplies of static relays.
- Identify level detector circuits and its applications.
- Identify comparator circuits and its applications.
- Identify phase shift circuits and its applications.
- Identify polarity detector circuits and its applications.

INTRODUCTION

The static relay schemes are built up from a number of basic circuits to form the most complex relay designs. These circuits are assembled using electronic components, but large jumps have now been made by the semiconductor manufacturers in producing large-scale integrated circuits to utilize multi-functions of relay operations.

BASIC CIRCUITS EMPLOYED IN STATIC RELAYS

- Power Supply for Static Relays.
- Smoothing and filter circuit.
- Level detector circuit.
- Fault detector circuit.
- Comparator circuit.
- Phase shift circuit.
- Precision rectifier circuit.
- Time delay circuit.
- Amplitude and phase comparator.
- Polarity detector circuit.
- Zero crossing detector.
- Trip circuit.

These basic circuits are either built up by discrete components or integrated circuits. They are tied together and supported on printed circuit boards (PCB) as the flow of the static protective relay scheme.

POWER SUPPLY FOR STATIC RELAYS

Power supply is an important device for most protective devices including static relays to drive all the internal circuits, the command signals, indicators, and until the output signals. Typically, we need 250 volt or 129 volt DC for tripping circuits and much lower voltage, 24 or 48 volt DC for relays, electronic equipment and other protective devices.

The supply voltages required for electronic protection equipment are generally provided by power supply systems using a reliable source, such as station battery. The constant supply voltages for electronic protection equipment must provide input to output isolation and keep interference voltages away from the protection equipment.

Only when all these requirements are met, simultaneously, the connected electronic protection equipment will function properly with reliability and operational security of protection systems.

Backup batteries are often used to ensure the supply of voltage to the electronic equipment during the disturbance in an event of interruption in the primary supply. The batteries are buffered and are always charged up by a charger so that their full capacity is always available when required during power interruption.

The function of a power supply system is to generate various supply voltages from the station battery voltage required by the electronic protection equipment. A typical arrangement for the supply of a protection system is shown in Fig. 3.2-1. The battery is kept fully charged by continuous trickle charging. In practice, the battery charger supplies the DC load during normal operation, with the battery in parallel, as shown in Fig. 1-2. Any failure of AC supply will cause the charger to shut down and the battery to feed the DC bus without interruption.

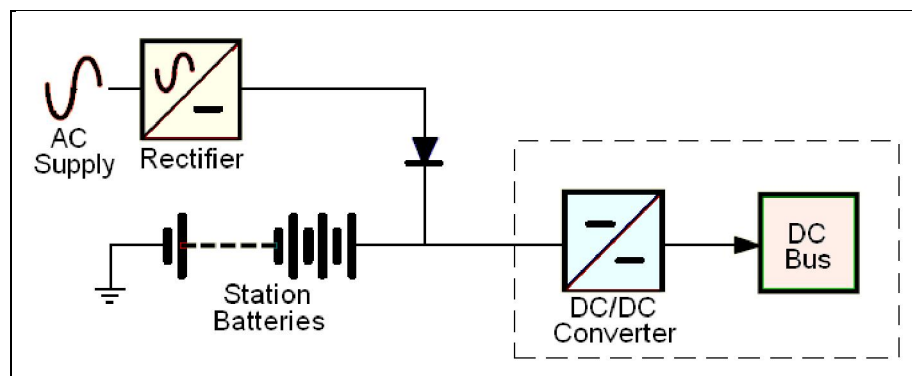


Fig. 3.2-1 Protection System Power Supply

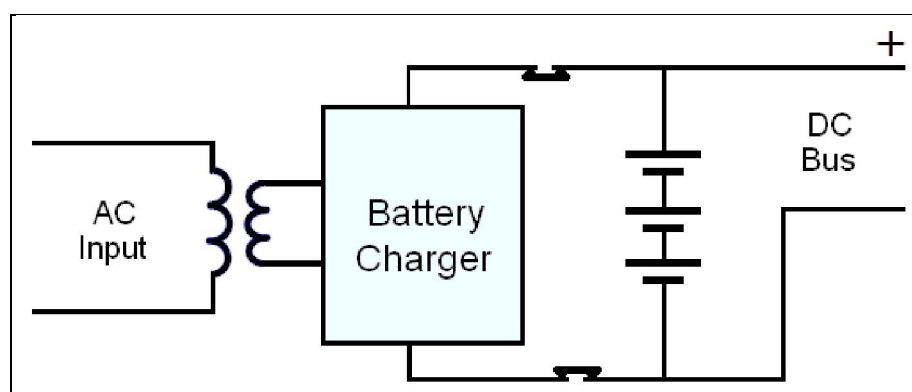


Fig. 3.2-2 Typical Battery Charger and Battery Hookup

RECTIFICATION AND SMOOTHING

The most common element in all power supply circuits is the transformer-rectifier circuit, as shown in Fig. 3.2-3. The 120 volt AC supplies a step-down transformer to feed the full-wave rectifier. The full-wave diode bridge rectifies the low level AC voltage into pulsating DC waveform, which is smoothed by the electrolytic filter capacitor. The filter capacitor must always be installed with correct polarity at the output of the rectifier or it will be destroyed and may cause explosion and bodily injury. The capacitor may be subjected to stress from voltage spikes due to switching transients and lightning and to prevent this, a Metal Oxide Varistor (MOV: Two back-to-back Zener diodes) is connected on the secondary side of the transformer. A bleeding resistor (R_{BLEED}), also acting as a minimum load, is connected across the DC output to discharge the electrolytic capacitor quickly when the input power goes off for some reason or the other.

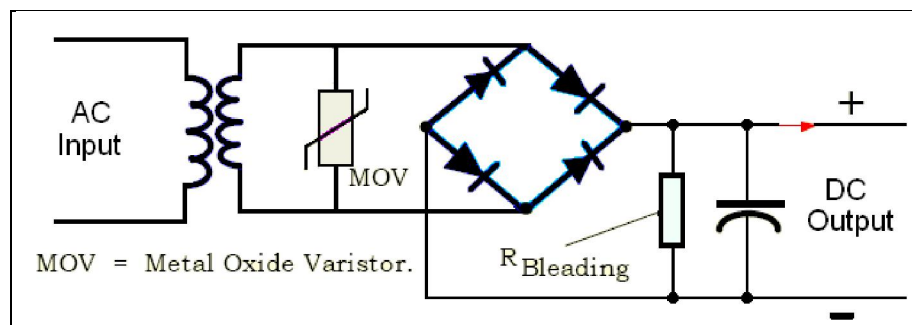


Fig. 3.2-3 Simple DC Power Supply

The regulator at the filtered output of the rectifier, as shown in Fig. 3.2-4 protects the load from damage due to voltage fluctuations.

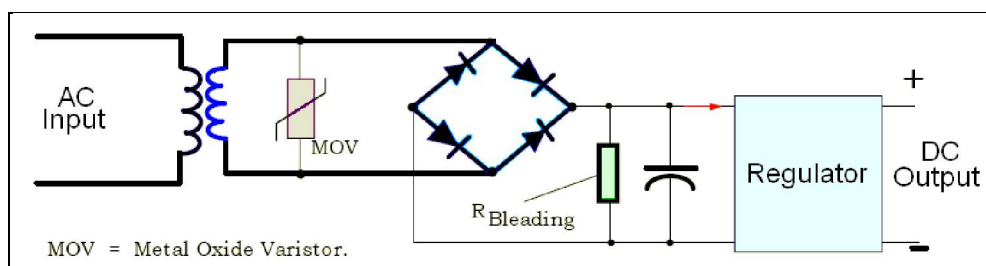


Fig. 3.2-4 Simple DC Power Supply with Regulator

SERIES-PASS VOLTAGE REGULATOR

Fig. 3.2-5 shows the series-pass transistor voltage regulator. All of the DC load current passes through the series connected transistor. The regulator output voltage is compared with the set-point voltage (V_{REF}) and the resultant signal is fed into an Error Detector/Amplifier. The amplifier (another transistor or an integrated circuit) provides negative feedback to the base of the series-pass transistor. This, in turn, controls the volt drop (V_{CE}) across the transistor and, consequently, the voltage output to the load.

$$V_O = V_{in} - V_{CE}$$

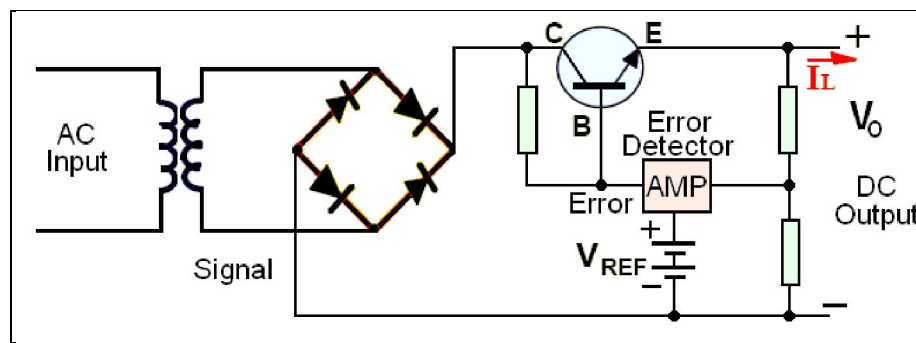


Fig. 3.2-5 Series-Pass Transistor Voltage Regulator

In this case, the series-pass transistor is neither cutoff nor saturated, but always in active region of operation. The output voltage is kept constant at the cost of varying power loss (P_{LOSS}) across the series-pass transistor by feedback-controlled base-drive.

$$P_{LOSS} = V_{CE} \times I_L \quad \text{Watts}$$

EXAMPLE 1-1

Given Fig. 3.2-5 for Series-Pass Transistor Voltage Regulator, an output voltage of 24VDC and DC input voltage of 52VDC at 10A output current would constitute a power loss of _____ Watts.

- | | |
|--------|------------------|
| a) 240 | b) 520 |
| c) 280 | d) None of above |

SOLUTION

$$P_{\text{LOSS}} = V_{\text{CE}} \times I_{\text{L}} = (V_{\text{IN}} - V_{\text{O}}) \times I_{\text{L}} = (52\text{V} - 24\text{V}) \times 10\text{A} = 28\text{V} \times 10\text{A} = 280\text{W}$$

SWITCHMODE VOLTAGE REGULATOR

The switching regulator is shown in Fig. 3.2-6. The series pass transistor is repeatedly turned on (saturated) and switched off (cutoff) by DC pulses generated by a high frequency oscillator. The principle of operation involves in charging the inductor and an electrolytic capacitor during on-time (T_{ON}) without causing any saturation and then discharging the capacitor, partially, and stored energy in the inductor during off-time (T_{OFF}) through the high speed switching (fly-wheel) diode to supply the load current. The output voltage is a linear function of DC input voltage and the switching Duty Cycle.

$$\text{Duty Cycle} = T_{\text{ON}} / (T_{\text{ON}} + T_{\text{OFF}})$$

$$V_{\text{O}} = V_{\text{IN}} (T_{\text{ON}} / (T_{\text{ON}} + T_{\text{OFF}}))$$

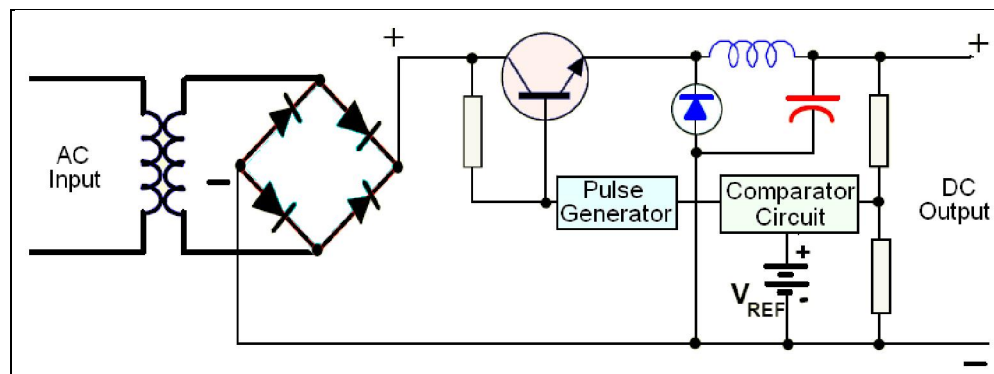


Fig. 3.2-6 Switching Series-Pass Transistor Voltage Regulator

The switching Duty Cycle is controlled by the negative feedback from voltage sampling circuit corresponding to the output voltage level and/or load current

As the output voltage tends to increase, the Duty Cycle decreases so that the transistor is OFF for longer period than it is ON, consequently, decreasing the on-time (T_{ON}) and resulting output voltage (V_{O}) and vice versa.

Example 3.2-2

Given Fig. 3.2-6 for Switching Series-Pass Transistor Voltage Regulator, for 24VDC output from 120VDC input. Determine the Duty Cycle of the oscillator.

SOLUTION

$$\text{Duty Cycle (D.C.)} = T_{\text{ON}} / (T_{\text{ON}} + T_{\text{OFF}})$$

$$V_O = V_{\text{IN}} (T_{\text{ON}} / (T_{\text{ON}} + T_{\text{OFF}}))$$

$$T_{\text{TOTAL}} = T_{\text{ON}} + T_{\text{OFF}} = 1 / \text{Frequency}$$

$$V_O = V_{\text{IN}} (T_{\text{ON}} / (T_{\text{ON}} + T_{\text{OFF}}))$$

$$24\text{V} = 120\text{V} \times \text{D.C.}$$

$$\text{D.C.} = 24\text{V}/120 = 20\%$$

There are many types of power supply that can be used according to the type of the source available AC or DC.

REGULATED POWER SUPPLY

Regulated power supply is used to provide the static relay with the required DC voltage to drive its basic circuits, when the source available is AC.

It consists of full wave rectifier circuit, smoothing circuit, regulator and filter circuit, Fig. 3.2-7. Power supply circuits can be very simple or very complex according to the required DC voltage, the maximum power output, the regulation required, the percentage efficiency and the degree of filtration.

Some circuits required three output terminals (Dual power supply) having +ve, -ve, and zero terminals. While the other circuits need positive and zero (ground) only.

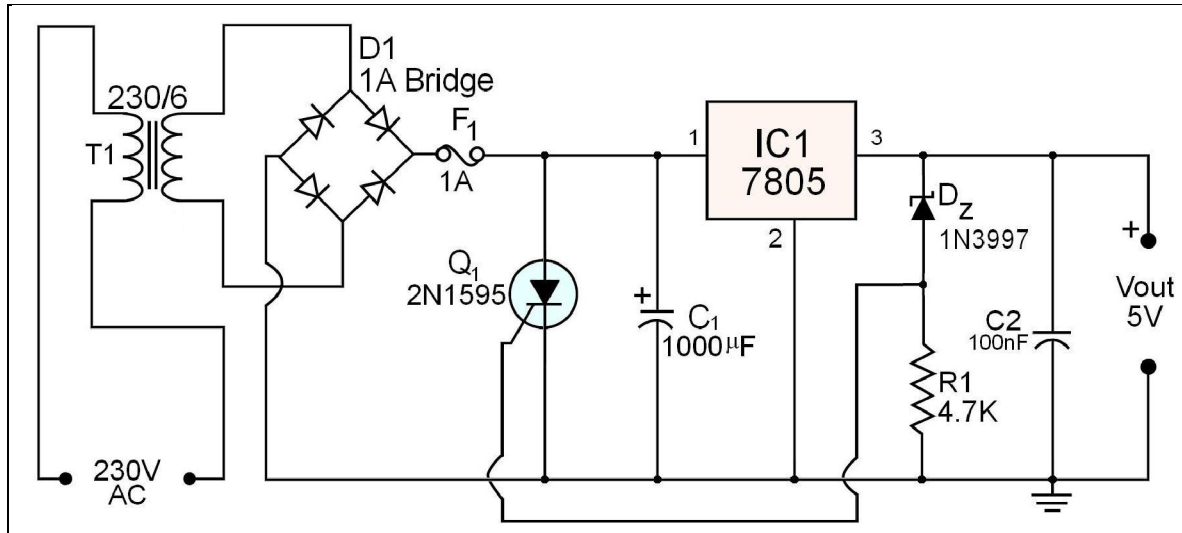


Fig. 3.2-7 Simple Regulated Power Supply

CIRCUIT CONTENTS

Transformer T ₁ :	Step down transformer 230/6V.
Rectifier bridge:	Four diodes to apply full wave rectifier.
Fuse F ₁ :	Protection device.
Capacitor C ₁ :	Smoothing capacitor.
IC1 7805:	Regulator to fix output voltage at +5VDC.
Capacitor C ₂ :	Filter capacitor for voltage ripples.
Zener diode D _Z :	It make a voltage divider with the R ₁ resistor to passes the reminder of the fixed output voltage to trigger the thyristor.
Thyristor Q ₁ :	At normal operation, Q ₁ is off because there is no feedback signal. At over voltage Q ₁ receives feedback gate signal then it conducts until the output is decreased again.

SWITCHED MODE POWER SUPPLY

Fig 3.2-8 shows a simple schematic diagram for Switch Mode Power Supply (SMPS). Switched Mode Power Supply utilizes a power semiconductor device (Static Switch), either in saturation or cut off mode at high frequency for a controlled period depending on the required output voltage and/or current to the load. And hence the

name, “Switched Mode”. It aims to save power dissipation at much higher efficiency (75-95%). At no load, the delivered power from the AC or DC supply is at its minimum value. As the load increases, the switching power device remains saturated for longer period to deliver more power at minimum power dissipation. SMPS can deliver power to many different loads at the same time. It also provides regulation, smoothing, filtering, and protection against overload.

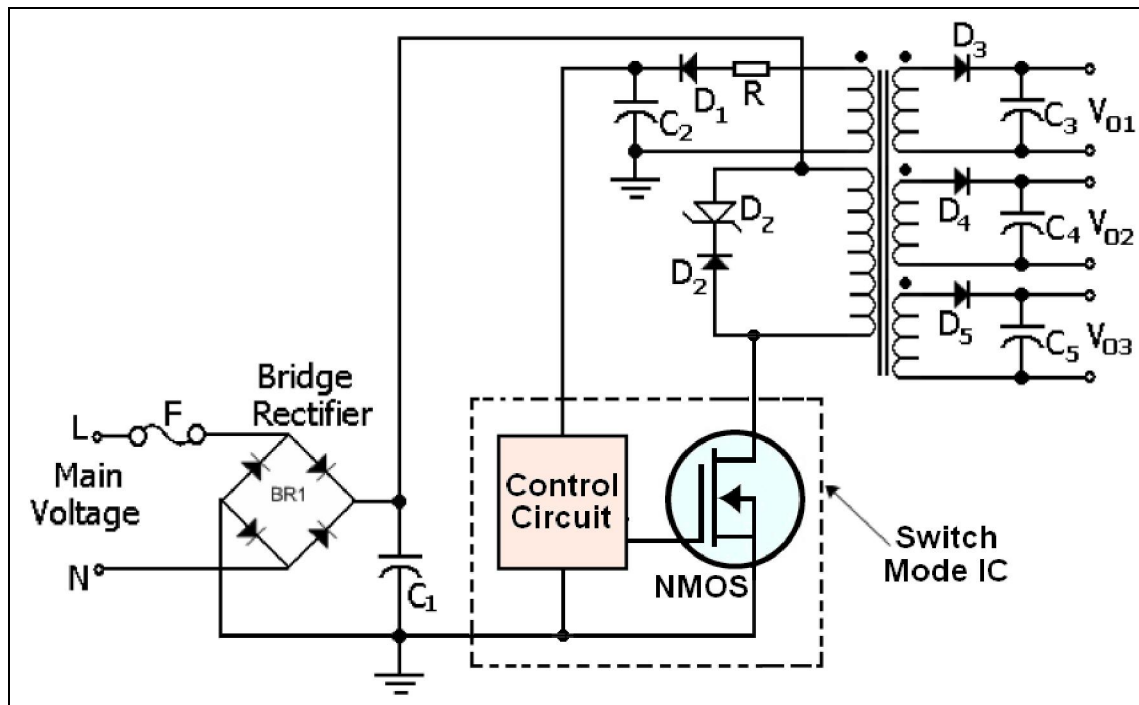


Fig. 3.2-8 Switched Mode Power Supply

In this circuit, the bridge rectifier circuit converts the AC supply to DC and smoother by capacitor C_1 . The NMOS transistor is switching when the gate signal is decreased. At no-load the control circuit receives high signal from the saturation transformer output, then the gate signal is high and no trigger is happened to the MOSFET and no power is delivered from the supply. At loading, saturation transformer start saturating, the voltage at control circuit is decreased, then the trigger is happened to the MOSFET and power is delivered from the supply.

The function of D_1 & C_2 circuit is to rectify the feedback signal to the control circuit. The output of the saturated transformer is multi-tap output to produce multi output voltage levels. Each output is rectified individually by D & C circuit

DC-TO-DC CONVERTER POWER SUPPLY

The DC-to-DC converter is used where DC isolation is required between circuits for electronic relays. A DC-to-DC converter comprises a free running oscillator transform and rectifier that changes DC from one level to another. The oscillator converts the high voltage DC from station batteries to high frequency AC through the use of saturable core transformer and high speed switching transistors, generally, in the following circuit configuration. The AC is stepped down by the step-down transformer secondary and then is rectified and filtered to produce low voltage DC for relay circuits.

A typical DC-to-DC converter is shown in Fig. 3.2-9. The transformer also provides isolation between the input and output voltages. The voltage regulator output feeds the square wave oscillator. The voltage supply to the square wave oscillator is regulated by the voltage and current feedback controls (not shown).

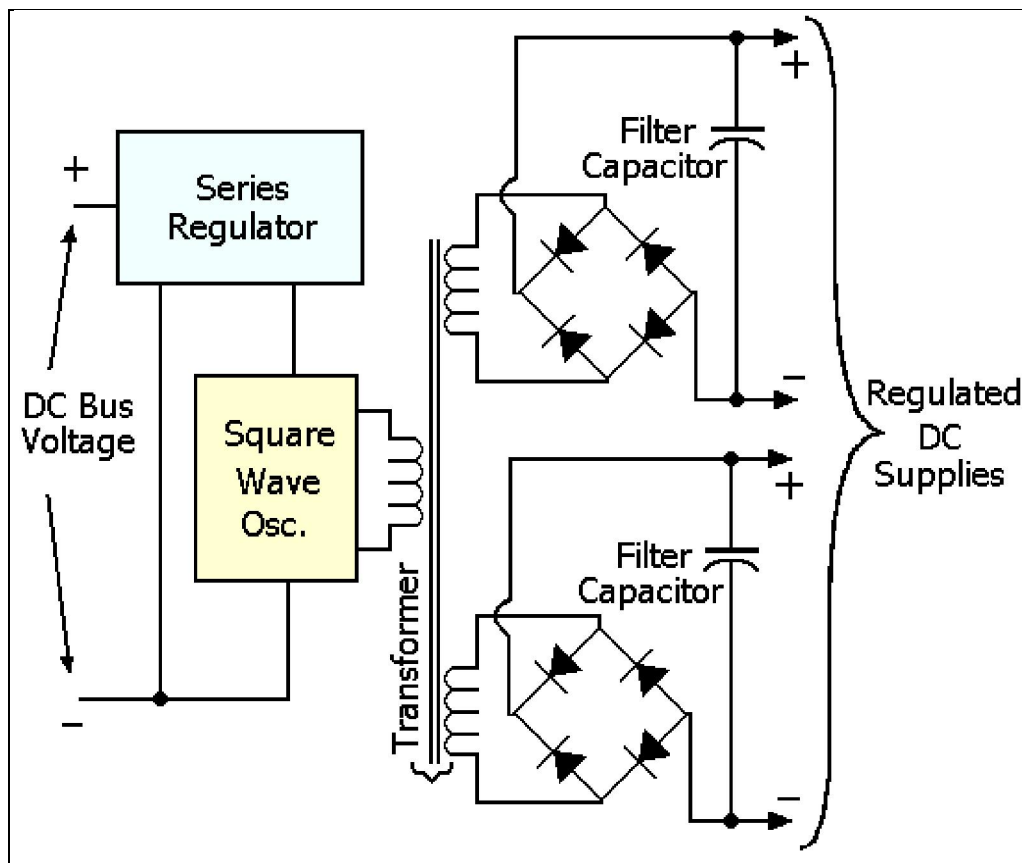


Fig. 3.2-9 DC-to-DC Converter Circuit Diagram

When the power source is AC, it is extremely important to protect the static relay against transient overvoltage or voltage spikes, which may be caused by normal operations on the power system such as switching or system faults. Protection for the relay is provided by connecting surge suppressors at appropriate locations.

Typically, the suppressor consists of a coupling capacitor in series with a resistor or Metal Oxide Varistor connected across the relay terminals or an inductor in series with the DC Bus leads. The MOV offers high resistance at low voltage, but breaks down to low resistance when the voltage rises above a pre-determined limit. Input leads to the relay should be shielded or screened and grounded to prevent interference. In some circuits, transformers are fitted with a grounded copper screen between the windings and chassis to prevent interference signals across the transformer.

SIEMENS POWER SUPPLY TYPE 7TN36 APPLICATION

The Siemens power supply, Type 7TN36 is used to provide the DC supply for the Relay 7TG32. Fig. 3.2-10 shows the functional block diagram components. A switching regulator operating at constant frequency of 20 kHz, which converts the input into constant DC voltage, unaffected by the input supply variations or load changes.

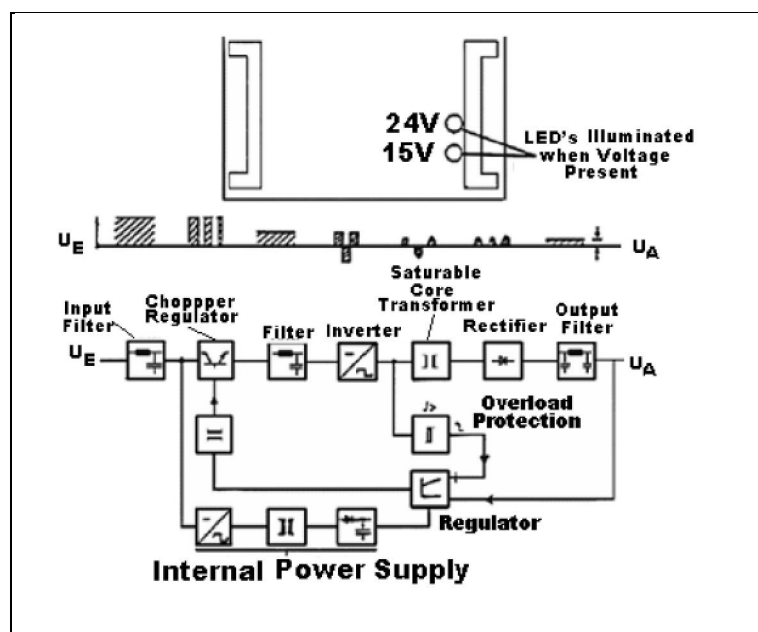


Fig. 3.2-10 Block Diagram for 7TN36 DC Supply Module

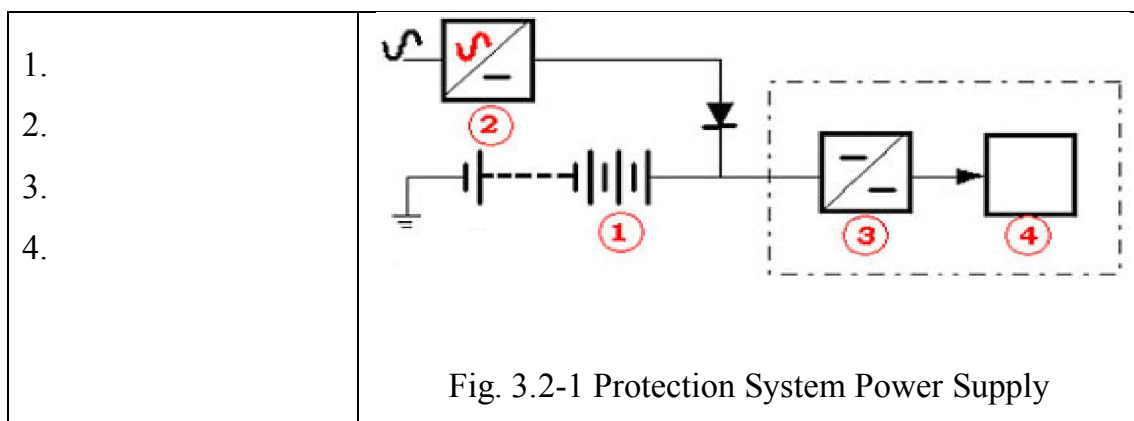
An inverter converts this constant DC supply into an AC voltage, which is fed to a saturable core transformer for isolating purposes. The transformer secondary voltage is rectified and smoothed. Either one or the other output voltage can be selected to act as feedback signal to the pulse width control system. An internal switching regulator rated for very low current for start up, consists of an inverter, saturable core transformer, rectifier and smoothing filter, supplying the power to the main regulator.

SUMMARY FOR POWER SUPPLY OF STATIC RELAYS

- Regulated power supply is used when the source available is AC.
- 250 volt or 129 volt DC are required for tripping circuits and much lower voltage, 24 or 48 volt DC for protective devices.
- All electrolytic filter capacitors must always be installed with correct polarity at the output of the rectifier or it will be destroyed and may cause explosion.
- As the output voltage tends to decrease, the Duty Cycle increases so that the transistor is OFF for shorter period (T_{OFF}) than it is ON, consequently, increasing the on-time (T_{ON}) and resulting output voltage (V_O) to increase and vice versa.

REVIEW EXERCISE

1. Higher voltage, 250 volt or 129 volt DC is used for tripping circuits in protective schemes.
 - a) True
 - b) False
2. Lower voltage, 24, 48 or 120 volt DC is used to power up protective relays.
 - a) True
 - b) False
3. Given Fig. 3.2-1 for Protection System Power Supply, identify the functional equipment as numbered.



4. A Metal Oxide Varistor (MOV) is connected on the secondary side of the transformer to protect the low voltage rectifier and other components from spikes due to switching transients and lightning.
 - a) True
 - b) False
5. In the series-pass transistor voltage regulator, as shown in Fig. 3.2-5, the transistor is _____.
 - a) Either cutoff or saturated, but never in active region of operation.
 - b) Neither cutoff nor saturated, but always in active region of operation.
 - c) Shorted or open circuit.
 - d) Cutoff, saturated and in active region of operation.

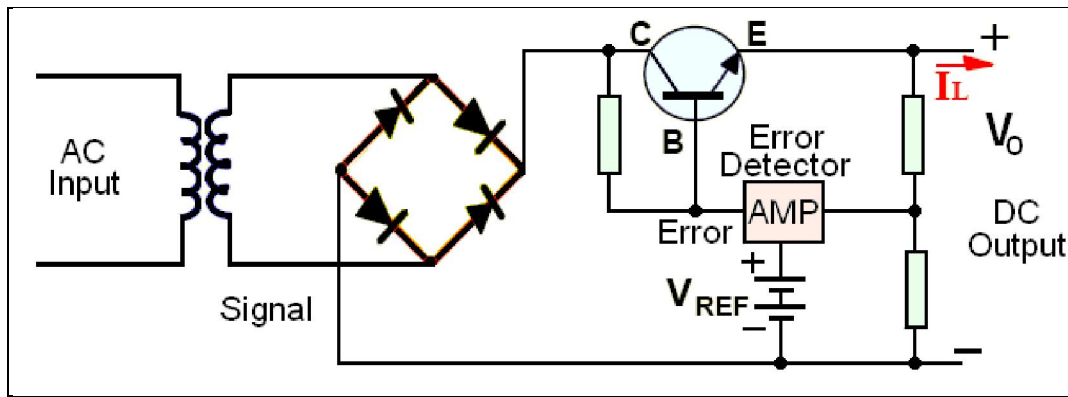


Fig. 3.2-5 Series-Pass Transistor Voltage Regulator

6. Given Fig. 3.2-5 for Series-Pass Transistor Voltage Regulator, an output voltage of 48VDC and DC input voltage of 52VDC at 10A output current would constitute a power loss of _____ Watts.
- a) 480 b) 520
- c) 20 d) None of above

SOLUTION

[illegible]

7. Given Fig. 3.2-5 for Series-Pass Transistor Voltage Regulator, for the same output voltage and load current, the lower the input voltage would produce _____ power dissipation across the power transistor.
8. Given Fig. 3.2-6 for Switching type Series-Pass Transistor Voltage Regulator, for 24VDC output from 120VDC input. The ON/OFF times for a Duty Cycle of 20% are _____, if the frequency of oscillator is 10kHz (**foc**).

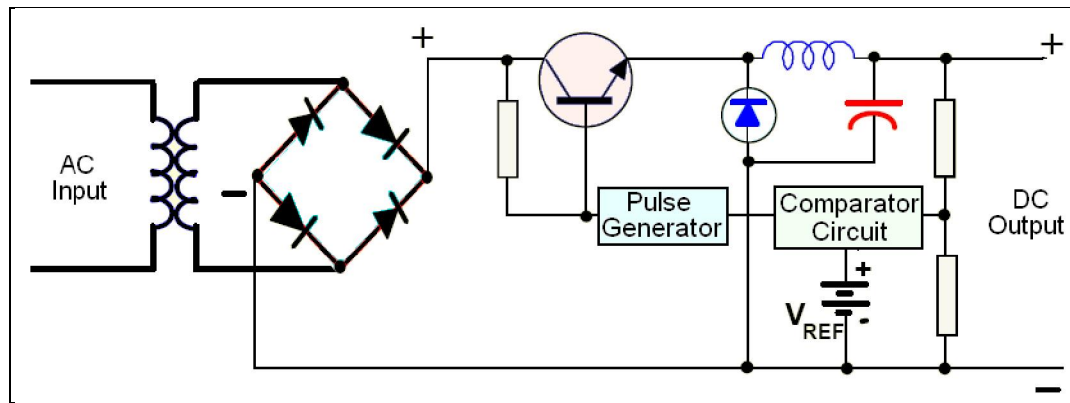


Fig. 3.2-6 Switching Series-Pass Transistor Voltage Regulator

SOLUTION

.....

.....

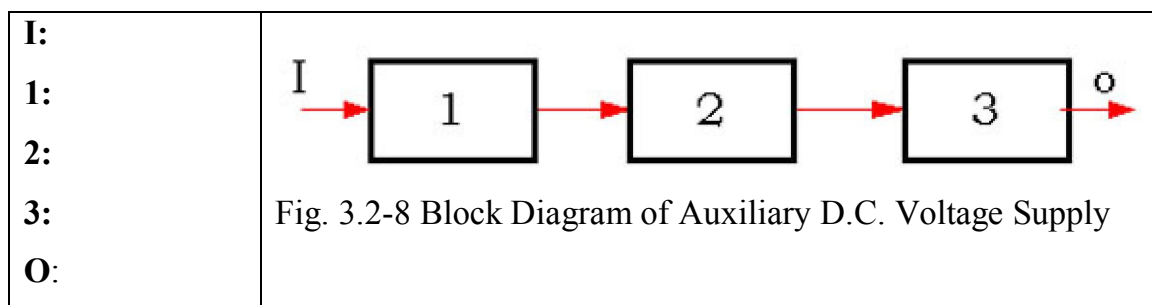
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9. Identify the functional blocks in Fig. 3.2-8, for the block diagram of an auxiliary DC voltage supply.



STATIC RELAY INPUT STAGE

The analogue inputs of the static relay are derived from the secondaries of CT/VT. These signals are connected to auxiliary CTs. The input stage of the static relay should comprise the following:

- CTs & VTs.
- Summation units.
- Current to voltage converter.
- Amplifier circuits.
- Auxiliary CTs.
- Smoothing and filters.
- Attenuation circuits.
- Clipping circuits.

PRECISION RECTIFIER CIRCUIT

However, the actual secondary values of CTs or VTs sometimes are very small down to a couple of m Volts at low frequencies, and it is required to be rectified.

These signals may be lost in the normal rectifier circuits. Precision rectifier is a circuit that rectifies the input actual physical quantities from the secondary of CTs or VTs without any reduction during rectification.

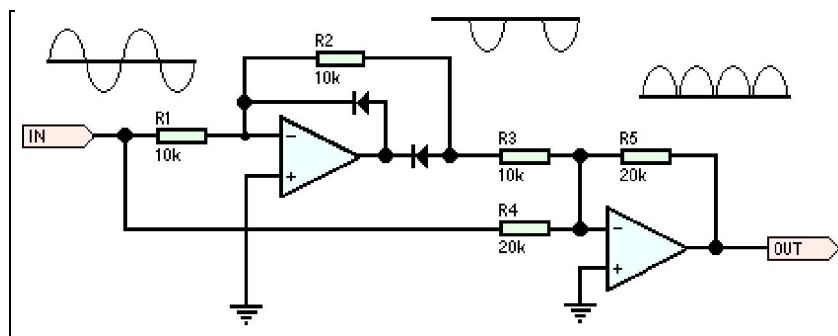


Fig. 3.2-11 Precision rectifier circuit

There are many types of precision rectifier circuits; half wave and full wave rectifier circuits that may be used as the application requires. This circuit is very sensitive to source impedance, so it is important to ensure that it is driven from a low impedance to accept the entire input signal and to reduce the burden of the CT. A typical full wave precision rectifier is shown in Fig 3.2.11.

FILTER CIRCUITS

The accommodation circuit is composed of smoothing, filter, clipping and amplifier circuit; it produces pure dc output that varies in voltage due to the change in actual value to simplify the following operations of the next circuits.

A typical band pass and low pass filter are shown in Fig 3.2-12 & Fig 3.2-13 respectively.

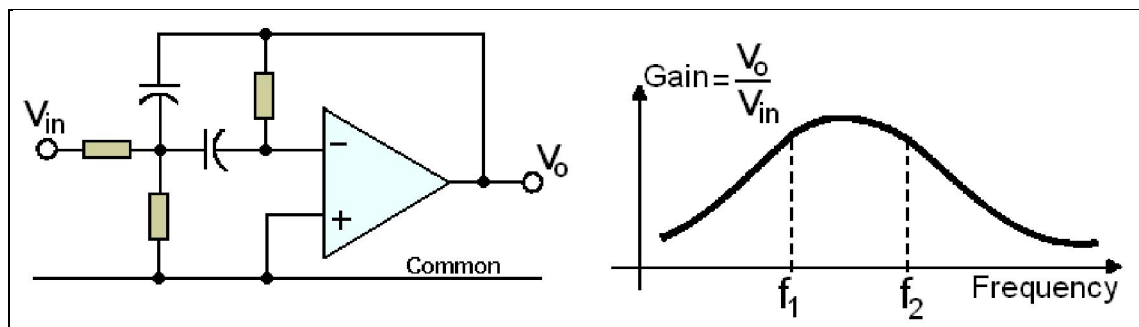


Fig. 3.2-12 Band Pass Filter

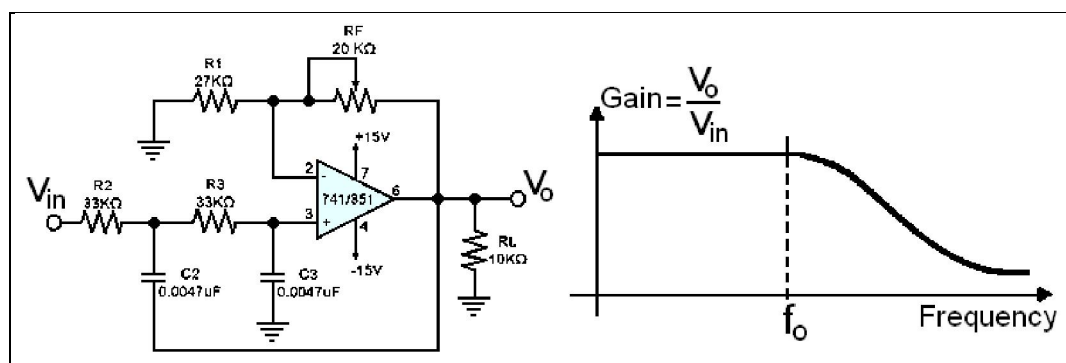


Fig. 3.2-13 Simple Low Pass Filter

TIMER CIRCUIT

Timer circuit is used to delay the relay output signal in order to adjust coordination between protective devices (main and back up). Timers may be found as an electronic circuits as shown in Fig 3.2-14. Clocks are available also in crystal quartz form, which operate by Piezo electric effect theory. Electronic timers can achieve higher precision than electromechanical timers within fraction of microsecond.

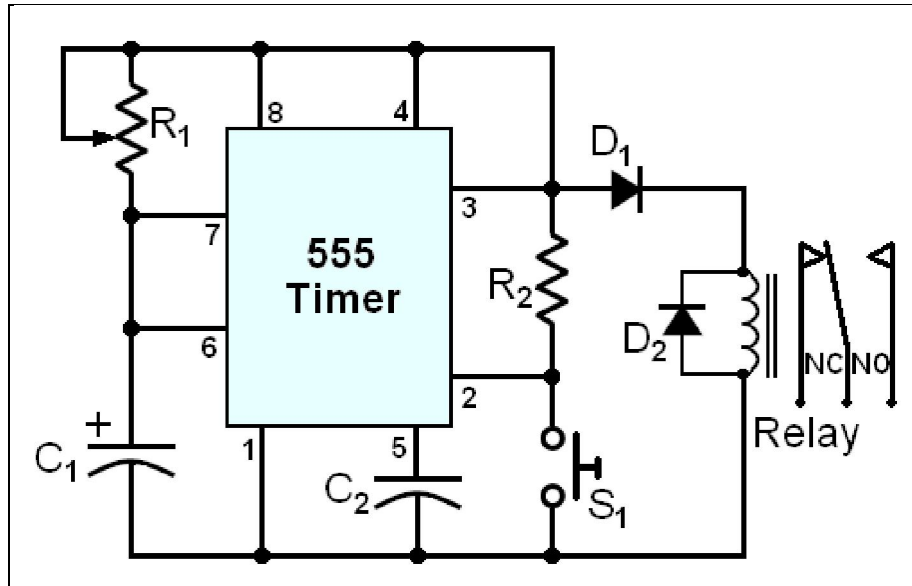


Fig. 3.2-14a Timer circuit used to control auxiliary relay action

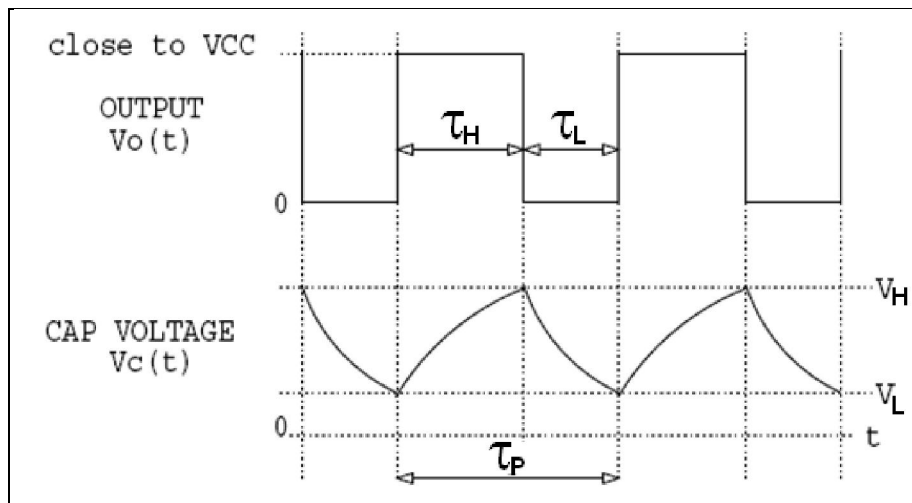


Fig. 3.2-14b Typical Waveforms of the Astable Circuit with the 555 Timer

$$\tau_L = R_1 C_1 \ln 2 = 0.693 R_1 C_1$$

$$\tau_H = (R_2 + R_1) C_1 \ln 2 = 0.693 (R_2 + R_1) C_1$$

where τ_P is a time constant or period time.

The period of the waveform is: $\tau_P = (R_2 + 2R_1) C_1 \ln 2$

$$f_P = 1/\tau_P$$

The output waveform duty cycle D is:

$$D = \tau_H/\tau_P = \tau_H/(\tau_H + \tau_L) = (R_2 + R_1)/(R_2 + 2R_1)$$

LEVEL DETECTORS

A level detector is a functional circuit in a protective relay, which determines the level of its inputs with reference to a predetermined setting. When the input (I) in Fig. 3.2-15, exceeds the level (L), the output (O) of the level detector through the amplifier drives the output stage of the protective relay initiating a Trip signal.

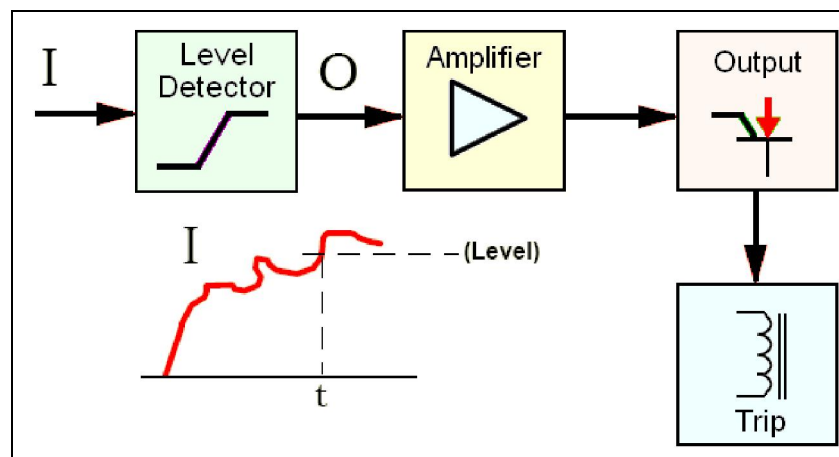


Fig. 3.2-15 Block Diagram of Typical Level Detector

NPN TRANSISTOR LEVEL DETECTOR

Consider the Common Emitter circuit, as shown in Fig. 3.2-16, with an NPN transistor. When Base-Emitter is biased with a negative voltage (V_R) and the input signal is less than or equal to the bias value in opposite polarity, no emitter current can flow.

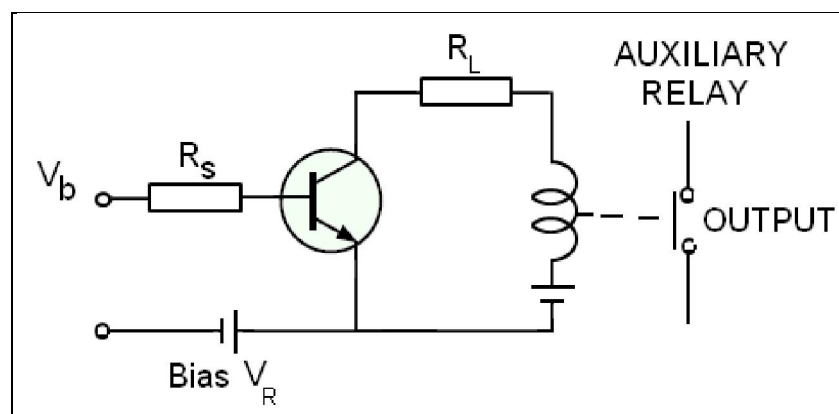


Fig. 3.2-16a Discrete NPN Transistor Level Detector Circuit

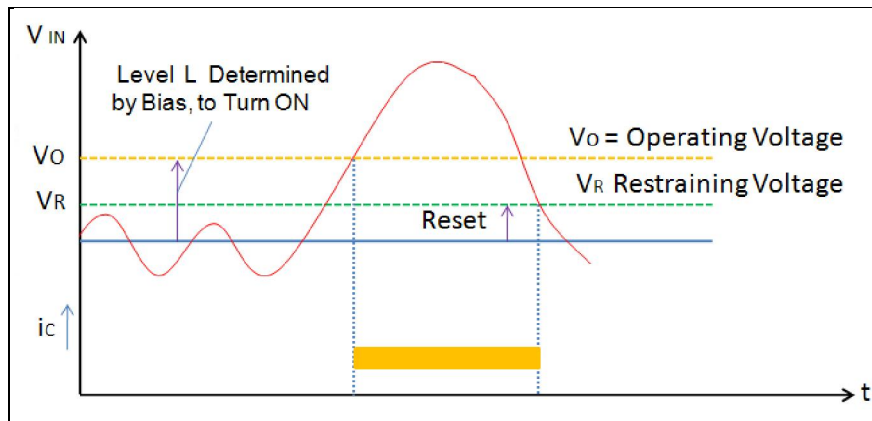


Fig. 3.2-16b Discrete NPN Transistor Level Detector Input/Output

The negative base bias provides the noise immunity to the input circuit equal to the bias value.

When the input signal V_{in} reaches $V_b = (+V_r + 0.7)$, the transistor is turned on and collector current (I_c) flowing through the transistor, energizes the auxiliary relay coil.

PNP TRANSISTOR LEVEL DETECTOR

Referring to Fig. 3.2-17, the input signal V_{in} to level detector should have desired level to make the PNP transistor conducting. When Base-Emitter is biased with a positive voltage (V_R) and the input signal is less than or equal to the bias value in opposite polarity, no emitter current can flow.

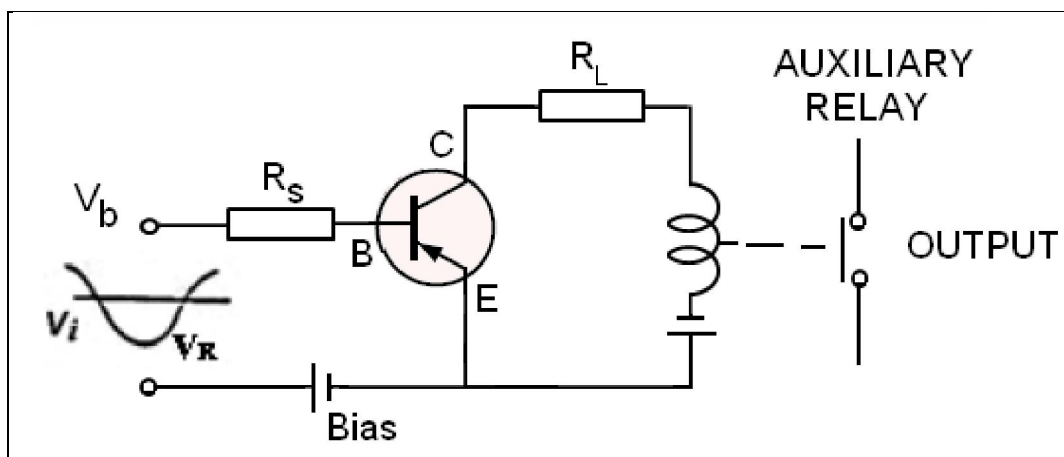


Fig. 3.2-17 Level Detector with PNP Transistor

The positive base bias provides the noise immunity to the input circuit equal to the bias value. When the input signal V_{in} exceeds the positive bias by approximately 0.7V in opposite polarity $V_b = (-V_r - 0.7)$, the transistor is turned on and collector current (I_C) flowing through the transistor, energizes the auxiliary relay coil.

SELF-BIASED TRANSISTOR LEVEL DETECTOR

Fig. 3.2-18 shows a self-biased transistor level detector using single power supply where the input signal is a rectified DC voltage. When the input signal exceeds the preset emitter voltage (V_{E1}) by 0.7V, the output at transistor T_2 is switched on energizing the trip coil in the collector circuit.

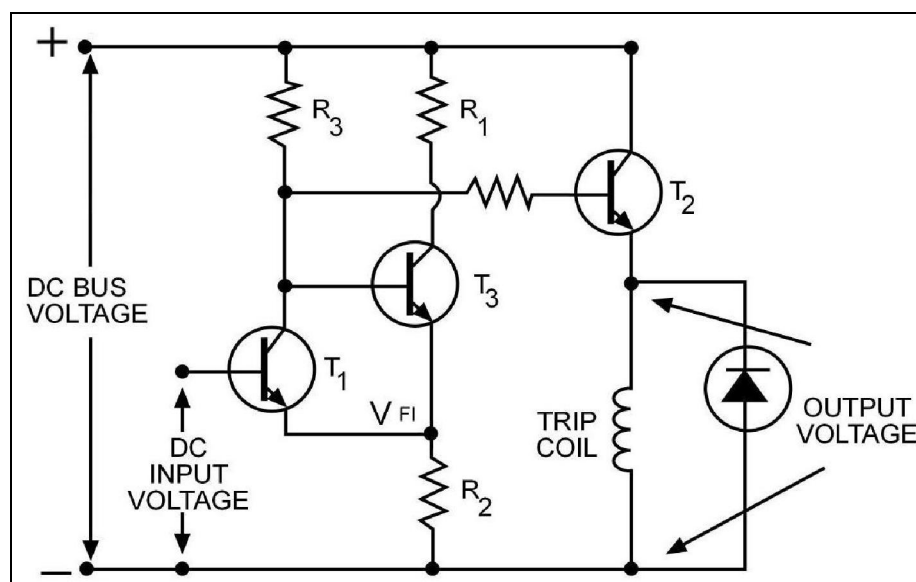


Fig. 3.2-18 Self-Biased Transistor Level Detector

In the absence of input signal ($V_{in} = 0V$), Transistor T_1 is biased off by its reverse biased Base-Emitter junction so that T_3 is turned on. The emitter bias is set by the voltage divider resistors R_1 and R_2 so that T_2 is also cutoff by T_1 collector being high. When V_{in} goes above V_{E1} by 0.7V, T_1 turns ON that in turn switches T_2 on to operate the trip coil. As the input signal falls below or equal to V_{E1} , T_1 and T_2 switch off. The reverse-biased diode across the coil protects the transistor from getting damaged by reverse polarity when the T_2 is just switching off.

NON-INVERTING OPAMP LEVEL DETECTOR

As shown in Fig. 3.2-19, an opamp may be used as a level detector. In normal opamp circuits, negative feedback is applied between output and inverting terminal for controlled gain in amplifier/attenuator applications. In protective relays, positive feedback is applied between output and non-inverting terminal providing hysteresis of few millivolts with open-loop gain in comparator/level detector applications for smooth transition of output signal without oscillation around zero-crossing. In a non-inverting opamp comparator/level detector, as shown, when the input is equal to or above the preset level, the output transition goes high in phase with the input and stays high until input signal falls below the preset voltage level.

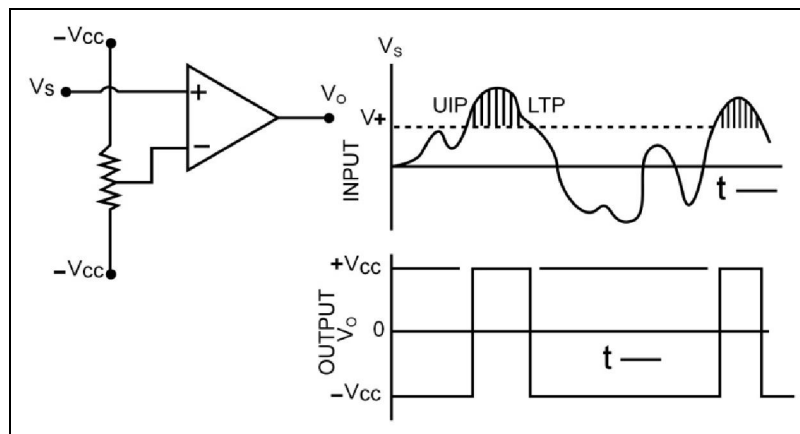


Fig. 3.2-19 Non-Inverting Op-amp Comparator/Level Detector

INVERTING OPAMP COMPARATOR/LEVEL DETECTOR

As shown in Fig. 3.2-20, the upper and lower trigger points are controlled by resistor R_3 . R_1 and R_2 set the initial bias for Upper Trigger Point (UTP) at the non-inverting input terminal. Reducing R_1 increases the Upper Trigger Point (UTP) and vice versa. When the input signal at the inverting input terminal is lower than the UTP, the output is high ($V_{CC} - 1 \approx V_{CC}$), so that R_1 and R_3 are in parallel to V_{CC} and the trip coil is de-energized:

$$UTP = V_{CC} / ((R_1/R_2) + R_2)$$

When the input signal at the inverting input terminal is equal to or higher than the UTP, the output is low (say 0V), so that R_2 and R_3 are in parallel to Ground (GND) and the trip coil is energized:

$$LTP = V_{CC} / (R_1 + (R_2 // R_3)) \times (R_2 // R_3)$$

The hysteresis voltage is the difference of the UTP and LTP giving the noise immunity for the input signal to eliminate the false triggering:

$$\text{Hysteresis voltage} = UTP - LTP$$

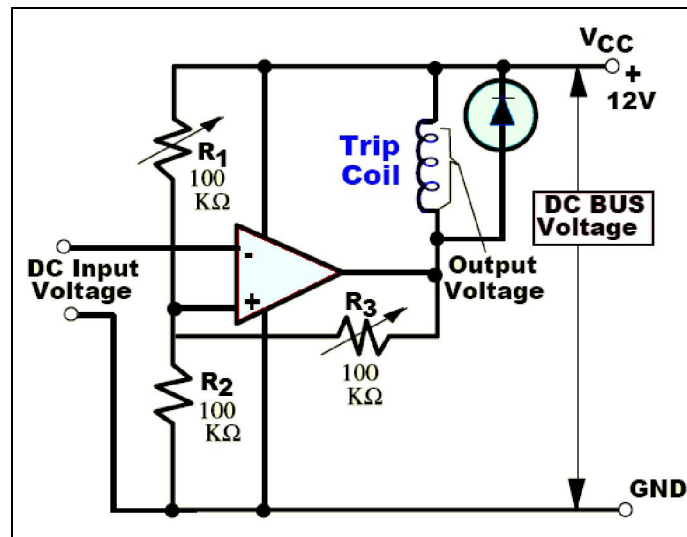


Fig. 3.2-20 Op-amp Comparator/Level Detector with Hysteresis

EXAMPLE 3.2-1

Given Fig. 3.2-20 for Op-amp Comparator/Level Detector with Hysteresis, determine:

- $UTP = V_{CC} / ((R_1 // R_3) + R_2) \times R_2$
- $LTP = V_{CC} / (R_1 + (R_2 // R_3)) \times (R_2 // R_3)$
- Hysteresis voltage

SOLUTION

- $UTP = V_{CC} / ((R_1 // R_3) + R_2) \times R_2 = 12V / (100k // 100k) \times 100k = 8V$
- $LTP = V_{CC} / (R_1 + (R_2 // R_3)) \times (R_2 // R_3)$
 $= 12V / (100k + (100k // 100k)) \times (100 // 100) = 4V$
- Hysteresis voltage = $UTP - LTP = 8V - 4V = 4V$

DISCRETE SCHMITT TRIGGER AS LEVEL DETECTOR

As shown in Fig. 3.2-21, transistor Q_1 is normally cutoff and Q_2 is conducting setting the bias V_{E1} depending on the gain of Q_2 (normally, saturated). When the input signal (V_i) goes higher than V_{E1} by 0.7V, Q_1 is saturated removing the driving potential B_2 . Q_2 stops conducting and the output voltage (V_o) goes high ($V_{oHI} = V_{CC}$). When V_i falls below V_{E1} by 0.7V, Q_1 stops conducting and Q_2 is driven into saturation. The low output voltage (V_{oLO}) is determined by voltage divider resistors R_4 and R_5 and $V_{CE2}(\text{SAT})$ of transistor Q_2 :

The Upper Trip Point is determined by voltage divider resistors R_4 and R_5 and V_{BE1} of transistor Q_1 when Q_2 is saturated (input signal going low to high):

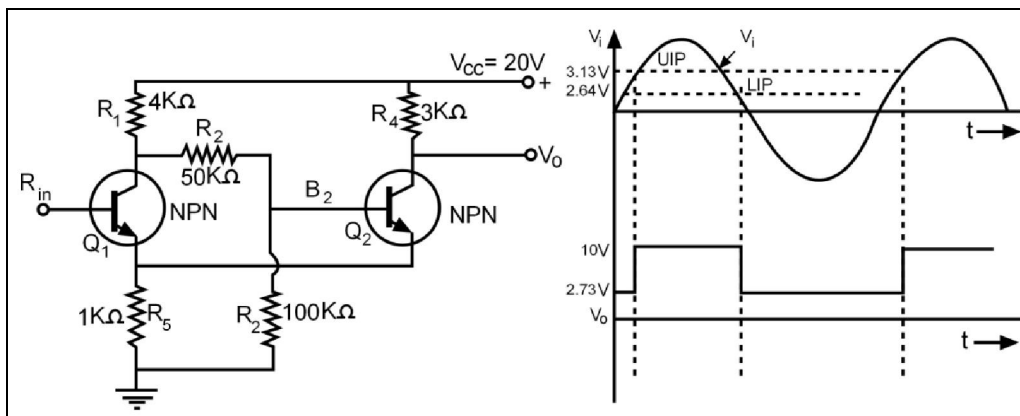


Fig. 3.2-21 Discrete Non-Inverting Schmitt Trigger with two NPN Transistors

The Lower Trip Point is determined by voltage divider resistors R_1 and R_5 and $V_{CE1}(\text{SAT})$ of transistor Q_1 when Q_2 is cutoff and Q_1 is saturated with input signal above V_{E1} (input signal going high to low):

LEVEL DETECTOR WITH NEGLIGIBLE DIFFERENTIAL

Fig. 3.2-22 Shows a Level detector with a negligible differential. Zener Diode $D1$ protects the level detector from being overloaded in case the battery supply overshoots the nominal value and resistor $R4$ acts as current limiting resistor in that case. $D2$ prevents damage due to reverse connection of supply. $D3$ prevents relay coil

generating excessive inductive voltage with reverse polarity that may damage T_2 when switching off. The RC filter consisting of R_5 and C_1 suppress input transients coming from the DC supply Bus.

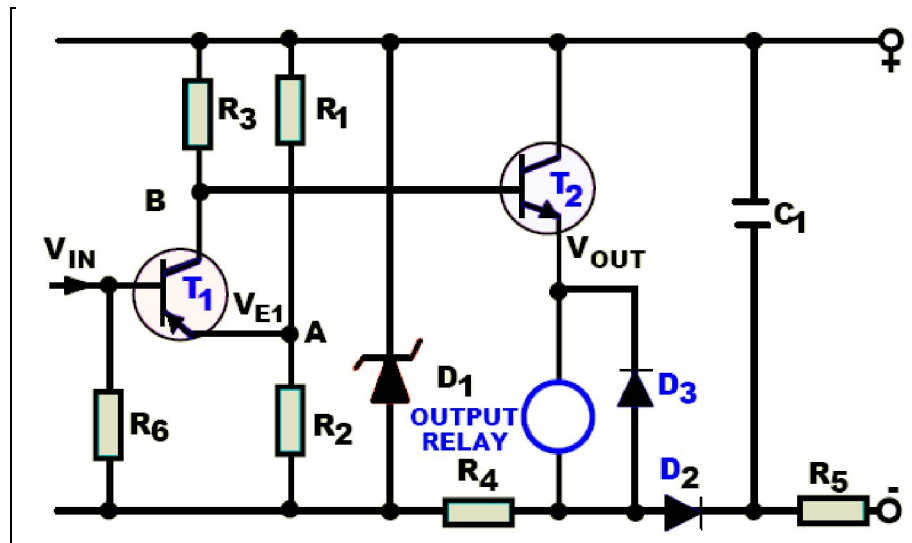


Fig. 3.2-22 Level Detector with Negligible Differential

In the absence of input signal ($V_{in} = 0V$), Transistor T_1 is switched off by its reverse biased Base-Emitter junction. The emitter bias at point A is set by the voltage divider resistors R_1 and R_2 so that T_2 is also cutoff by T_1 collector being high. When V_{in} goes above V_{E1} by $0.7V$, T_1 turns on and that in turn switches T_2 on to operate the output relay. As the input signal falls below or equal to V_{E1} , T_1 and T_2 switch off. As there is no hysteresis ($\approx 0.7V$) in the circuit, the switching differential is negligible.

DISCRETE POLARITY DETECTOR

As shown in Fig. 3.2-23, a very sensitive level discrete polarity detector is used where an exact determination of zero crossing of AC waveform is required for synchronizing and minimizing noise in tripping. The transistorized Emitter-Coupled Logic (ECL) circuit, as shown, only requires a few millivolts input differential (A is positive with respect to B) to saturate TR_4 . The currents through TR_1 and TR_2 are initially balanced by the potentiometer bridging their emitters, so that $0V$ exists across TR_3 Base-Emitter junction (TR_3 off).

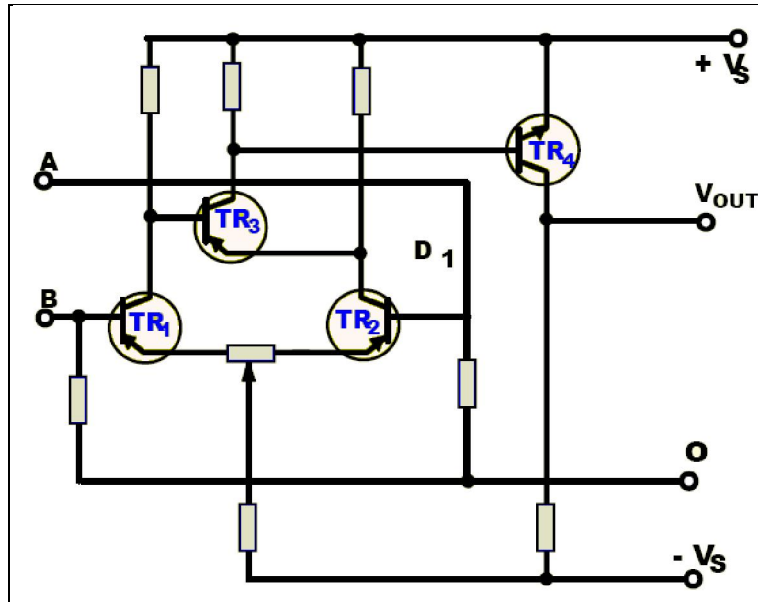


Fig. 3.2-23 Discrete ECL Polarity Detector

An input signal raises the potential of A relative to B, TR_2 conducts more than TR_1 drawing current through TR_3 . Conduction of TR_3 turns on TR_4 , in consequence, and produces an output signal across the output resistor at TR_4 collector terminal. When A is negative relative to B, the output signal is $-V_s$.

LINEAR INTEGRATED POLARITY DETECTOR

Fig. 3.2-24 shows more sensitive polarity detector with opamp without feedback operating in open-loop. In this case, the output reverses polarity typically from approximately $(+V_{CC}-1)$ to $(-V_{EE}+1)$ with respect to the input polarity so that the output is in phase with the input. This makes it easier to detect precisely when the sine wave crosses the 0V reference point. One of the main uses of polarity detector is to measure the phase difference, precisely, between two sine waves from two different sources. Phase comparison is used for directional relaying, as required in many types of protection schemes. As the operational amplifier has a very high voltage gain, typically of the order of 100,000, a small positive signal on the non-inverting input gives an output voltage transition of approximately $+V_{CC}-1$. Similarly, a small negative input voltage will give an output voltage of $-V_{EE}+1$. A sinusoidal input produces a square wave output voltage between $+V_{CC}-1$ and $-V_{EE}+1$ about the zero-

crossing points of the input wave. The two diodes in parallel with opposite polarities across the input terminals limit the input amplitude to $\pm 0.7V$ to avoid overloading of op-amp input circuit.

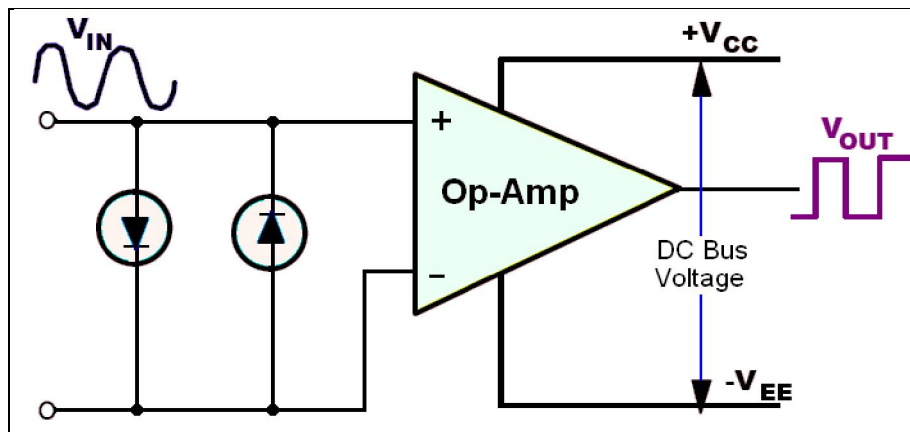


Fig. 3.2-24 Linear Polarity Detector using Opamp

Polarity detector circuit is used to check if the wave polarity is reversed or not for the DC signals. It can also compare waveform polarity with respect to another waveform. The circuit depends on the comparator action of the operational amplifier to switch V_{CC} to the output. A typical polarity detector circuit is shown in Fig. 3.2-24.

SUMMARY FOR LEVEL DETECTORS

- A level detector is a functional circuit in a protective relay, which determines the level of its inputs with respect to a preset level.
- All discrete level detectors operate around $0.7V$ above or below the set point.
- Negative feedback is applied between output and inverting input terminal for controlled gain in amplifier/attenuator applications.
- Positive feedback is applied between output and non-inverting input terminal for introducing hysteresis to switching output to eliminate false triggering and achieving smooth output transitions.
- A level detector with preset differential involves hysteresis to output switching transitions.

REVIEW EXERCISE

1. Identify the basic blocks of a typical level detector in Fig. 3.2-15.

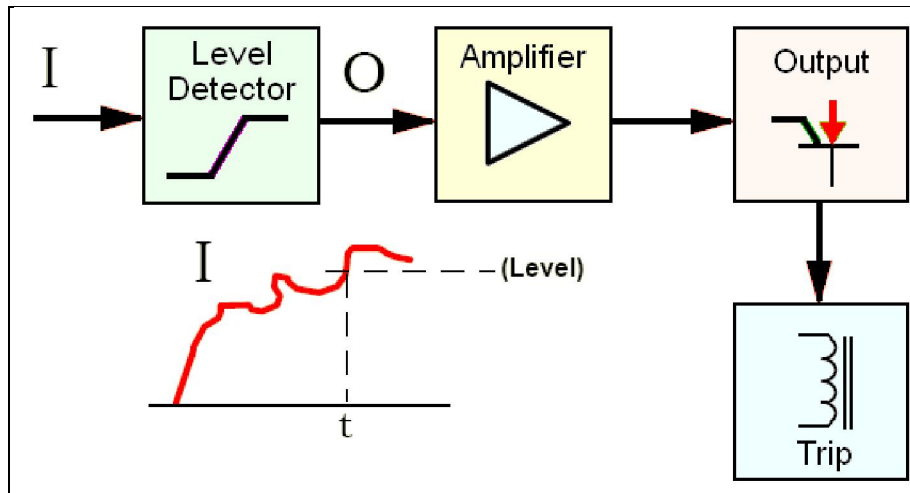
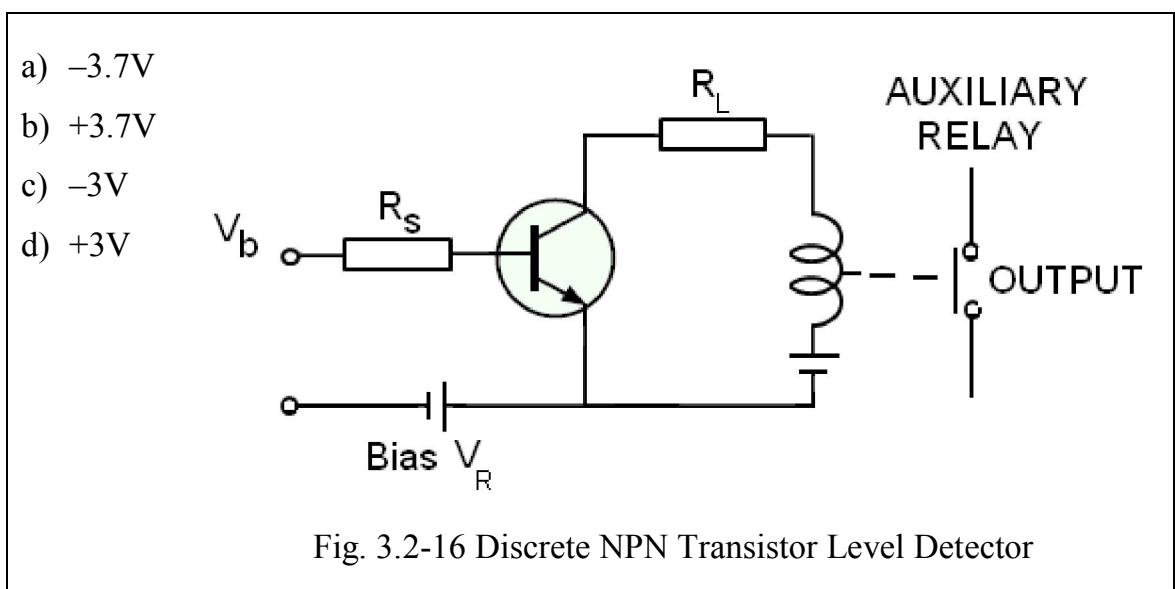


Fig. 3.2-15 Block Diagram of Typical Level Detector

Given Fig. 3.2-16 for Discrete NPN Transistor Level Detector When the input signal V_{in} reaches $V_b = \underline{\hspace{1cm}}$ V, the transistor is turned on and collector current (I_c) flowing through the transistor, energizes the auxiliary relay coil.



3. In Fig. 3.2-18 for the Self-Biased discrete level detector, when the input voltage exceeds V_{E1} by $0.7V$, the transistor T_2 is switched on to operate the trip coil.

- a) True
b) False

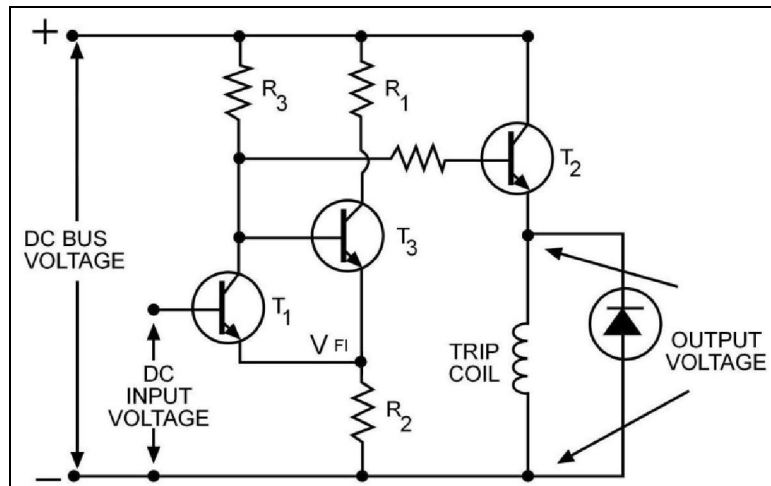


Fig. 3.2-18 Self-Biased Transistor Level Detector

4. In Fig. 3.2-18 for the Self-Biased discrete level detector, with no input signal _____:
- a) T_1 and T_3 are cutoff
b) T_1 and T_2 are cutoff
c) T_2 and T_3 are cutoff
d) T_2 and T_3 are conducting
5. Given Fig. 3.2-19 for Non-Inverting Opamp Comparator/Level Detector, draw the output waveform.

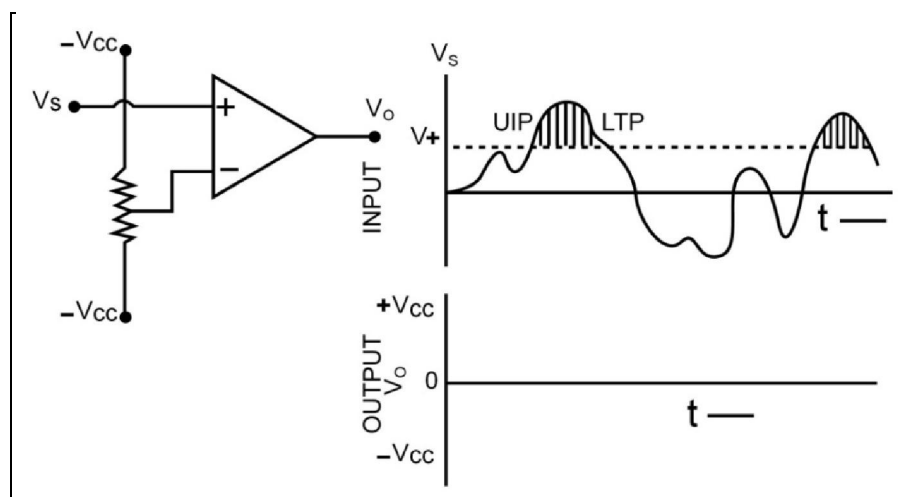


Fig. 3.2-19 Non-Inverting Opamp Comparator/Level Detector

6. Given Fig. 3.2-20 for Op-amp Comparator/Level Detector with Hysteresis (R_3 set to 47K), determine:

- a) UTP
$$UTP = \frac{V_{cc}}{(R_1//R_3) + R_2} \times R_2$$
- b) LTP
$$LTP = \frac{V_{cc}}{R_1 + (R_2//R_3)} \times (R_2//R_3)$$
- c) Hysteresis voltage

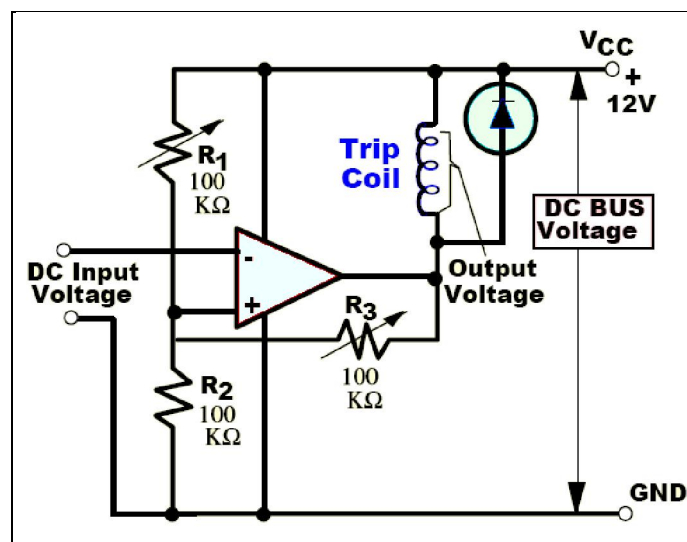


Fig. 3.2-20 Op-amp Comparator/Level Detector with Hysteresis

SOLUTION

7. Given the schematic diagram for a discrete Level Detector circuit, as shown in Fig. 3.2-22, answer the following questions:
- The _____ at the emitter of TR1 is determined by the voltage divider resistors R_1 and R_2 .
 - All transistors are biased off until the input signal exceeds the voltage reference V_R at the emitter of TR1 by approximately _____.
 - 0.7V
 - 1V

- c) 0.3V
d) 0V
- iii) When the input voltage exceeds the voltage reference V_R , both transistors turn off and the output relay is de-energized.
- a) True
b) False
- iv) The diode ____ protects the transistor T2 from getting damaged by the reverse polarity of the relay coil when de-energized.
- a) D1
b) D2
c) D3
d) D1 & D2
- v) Zener Diode D1 provides over voltage protection for the level detector in case the battery supply overshoots the nominal value.
- a) True
b) False
- vi) ____ provides protection for the level detector against reverse DC supply connection.
- a) D1
b) D2
c) D3
d) R6

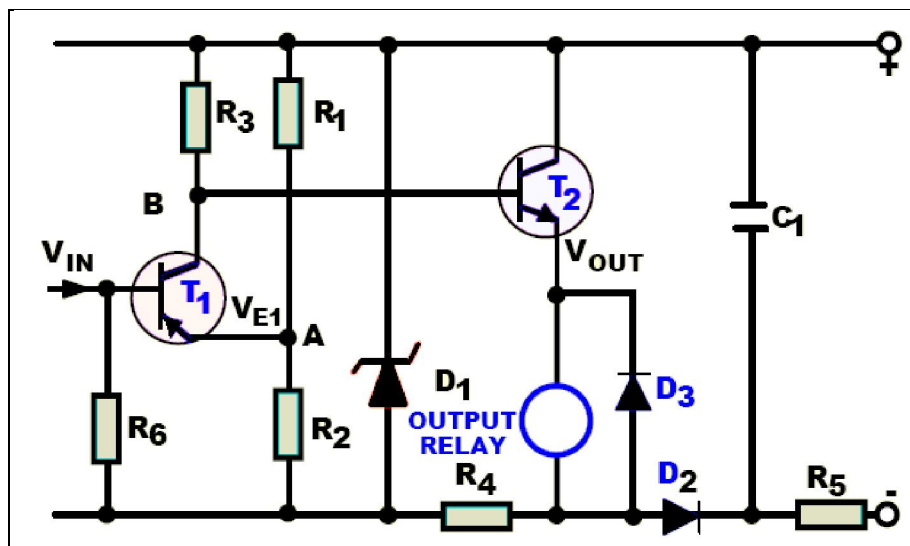


Fig. 3.2-22 Level Detector with Negligible Differential

8. As shown in Fig. 2-9 for discrete polarity detector:

- iii) When A is negative with respect to B, the output signal is _____.
 a) 0V b) +Vs
 c) -Vs d) None of above

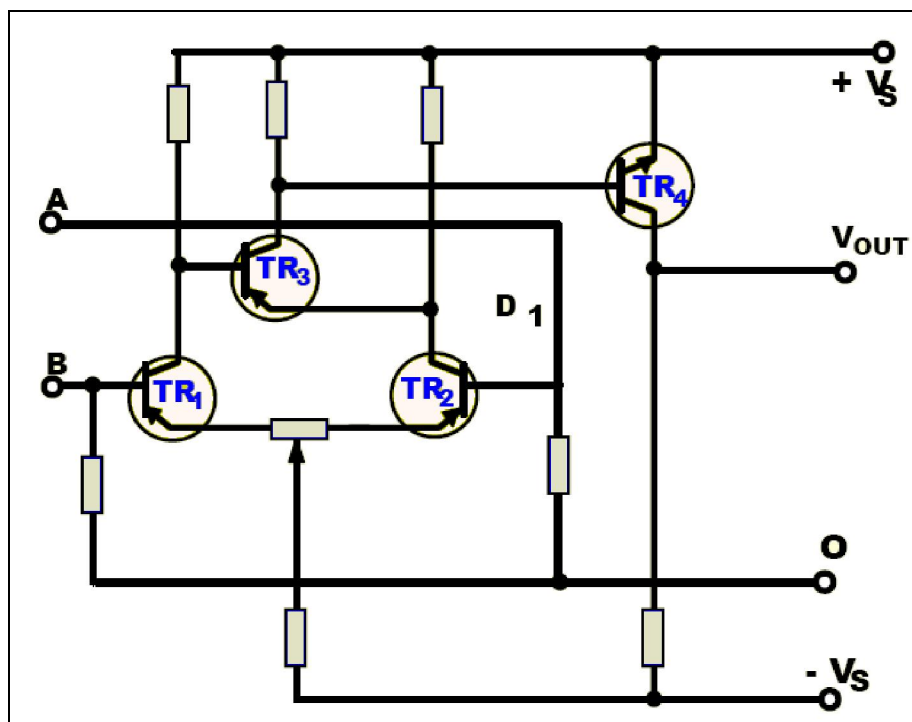


Fig. 3.2-23 Discrete ECL Polarity Detector

9. Given Fig. 3.2-24 for the non-inverting linear phase comparator circuit:
- i) The phase angle between the input and output signal is ____.
- a) 0° b) 90°
- c) 180° d) 270°
- ii) The two diodes in parallel with opposite polarities across the input terminals limit the input amplitude to ____ to avoid overloading of Op-Amp input circuit.
- a) $0.7V_{p-p}$ b) $1.4V_{p-p}$

c) $\pm 1.4V_p$

d) None of above

iii) The amplitude of output square wave in phase with the input signal varies approximately, from _____ to _____.

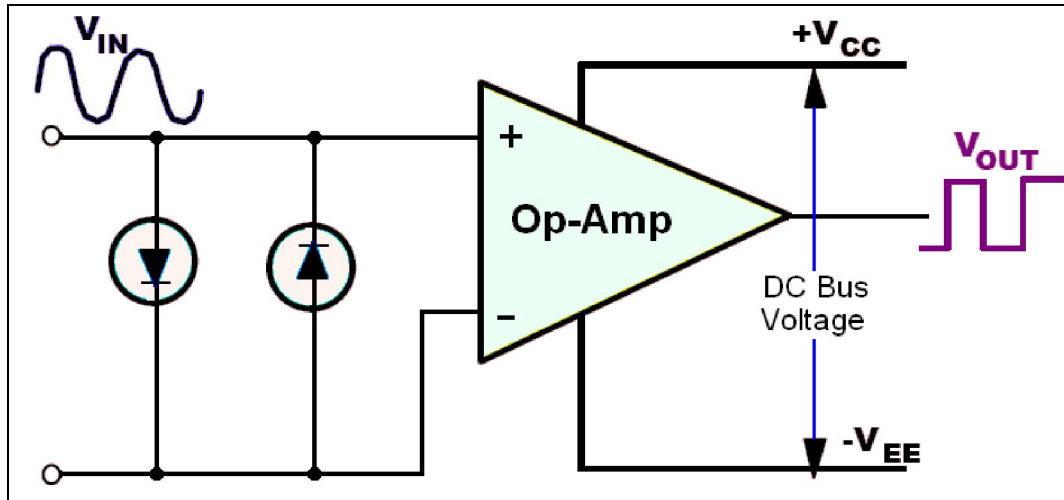


Fig. 3.2-24 Polarity Detector using Op-Amp

COMPARATOR CIRCUITS

CLASSIFICATION OF COMPARATORS

The comparator circuits are used in double acting relays to compare two quantities. As in a differential relay. The comparators are classified, as shown in Fig. 3.2-27.

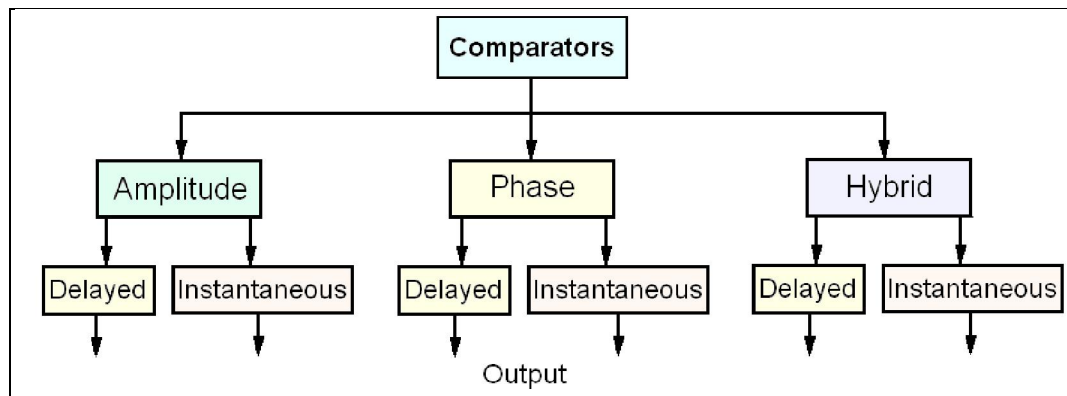


Fig. 3.2-27 Classification of Comparators

Comparator is a part of relay, which receives two or more inputs to be compared and gives output based on their comparison. Comparators are either instantaneous (direct) or time-delayed (integrated with respect to time). Comparators are either single-phase or poly-phase and can employ either amplitude or phase comparison or both. Hybrid type comparators combine the amplitude and phase comparators.

AMPLITUDE COMPARATORS

Amplitude comparator compares the magnitude of the two or more input quantities and gives an output, accordingly. The phase angle between the two or more inputs is not recognized by the amplitude comparator.

Fig. 3.2-28 shows a common type of Amplitude Comparator. The two incoming signals are rectified and connected in opposition, one to trip and one to restrain, resulting in a DC signal equal to the difference ($I_A - I_B$). The rectified signals are filtered, but the filter capacitor may introduce a time delay.

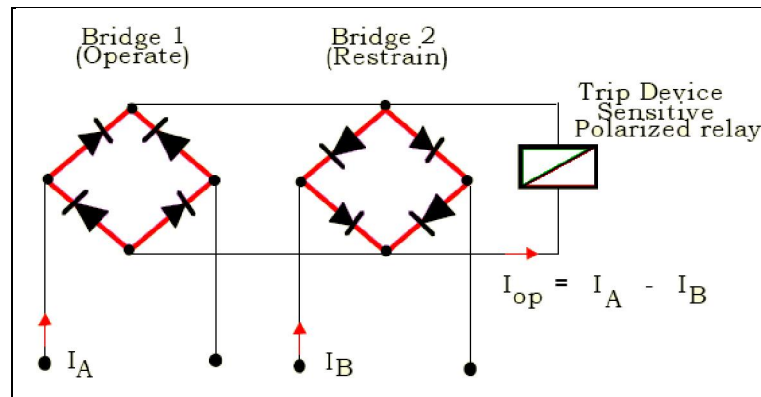


Fig. 3.2-28 Typical Amplitude Comparator

As shown in Fig. 3.2-29, I_A denotes the magnitude of complex function I_A to provide direct comparison. If $|I_A| > |I_B|$, the output $|I_A| - |I_B|$ of comparator is positive and negative, if $|I_A| < |I_B|$ and Zero, if $|I_A| = |I_B|$.

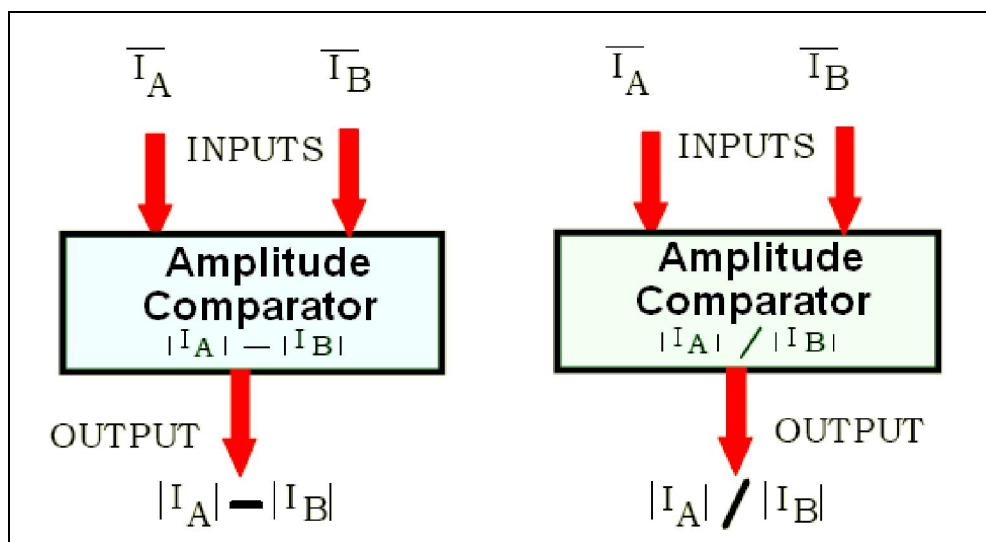


Fig. 3.2-29 Function of Amplitude Comparator

MAGNITUDE COMPARATOR WITH FIXED REFERENCE

The logic circuit, as shown in Fig 3.2-30, used for an Instantaneous Over-Current Unit is basically a DC level detector. The Input current from the current transformer is transformed to a voltage in the secondary of the input transformer. Back-to-back Zener diode Z_1 and resistor R_2 limit the current.

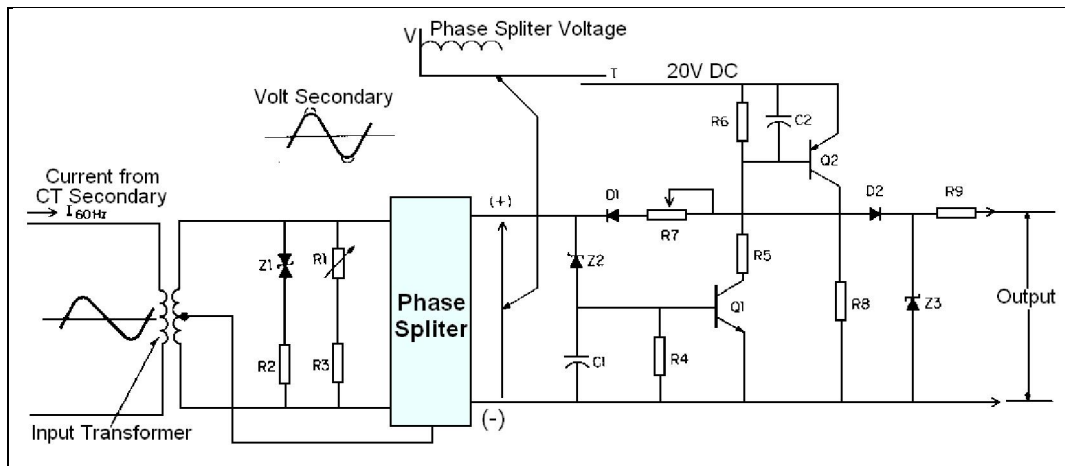


Fig. 3.2-30 Magnitude Comparator DC Level Detector
in Instantaneous O/C Unit

For low input currents the voltage is proportional to the current determined by R_3 and adjustable resistor R_1 . The minimum pickup is adjusted via the setting of R_1 where a low setting diverts more current through R_1 and R_3 and less to the Phase Splitter. The Phase Splitter consists of a resistor-capacitor network, a transformer and a bridge rectifier. The Phase Splitter output voltage is shown on the upper part of Fig. 3.2-30. When the Phase Splitter output voltage equals the Zener breakdown voltage of Z_2 , the resulting base current turns on Q_1 . That forward-biases Q_2 providing positive feedback (hysteresis) through R_7 and D_1 , compounding the effect of the Level Detector. The dropout current can be adjusted by potentiometer R_7 , normally set for a dropout pickup ratio of about 0.97. The 3% hysteresis provides the equivalent-of snap action and prevents chattering at current values close to minimum pickup. This type of circuit may also be used for Over-Voltage Relays.

PHASE SPLITTING OF INPUTS TO AMPLITUDE COMPARATOR

Phase splitting before rectification, as shown in Fig. 3.2-31, improves performance of the amplitude comparator. The AC input signal is split into six components each 60° apart. The greater the number of phases, the greater the amount of smoothing. Phase splitting shifts the phases by $+120^\circ$ and -120° (a^2 & a) in each input, making the AC

outputs differ in phase by 120° . The AC outputs are then fed to six diode rectifiers on each side giving six-phase rectification.

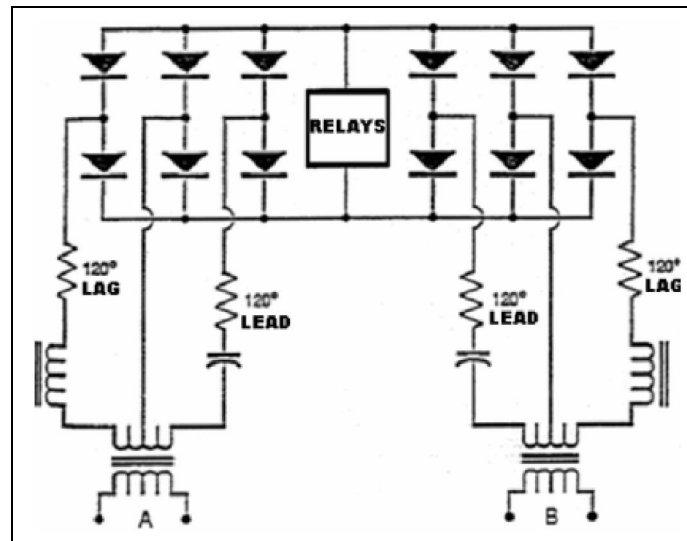


Fig. 3.2-31 Phase-Splitting of Inputs to Amplitude Comparator

This type of comparator gives continuous output signal. In one of the methods, the restraint signal is rectified and smoothed, while the operating input is rectified full wave but not smoothed. The peak of the operating signal must exceed the restraint level for operation of the relay, as shown in Fig.3.2-32.

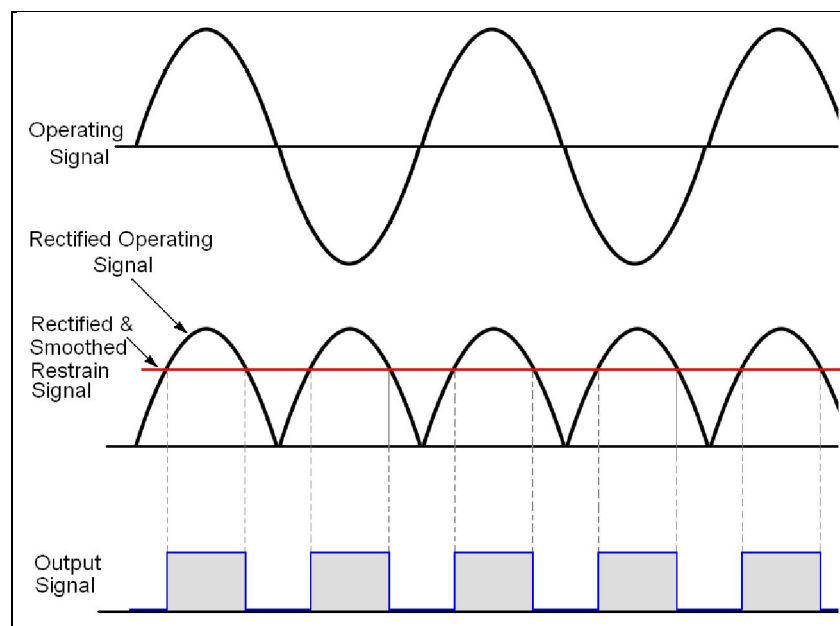


Fig. 3.2-32 Amplitude Comparator Output for Direct Comparison

The output stage receives a direct current, continuously, equivalent to $|I_A| - |I_B|$. The output stage of rectifier bridge comparators may have one of the following devices:

- Permanent Magnet Moving Coil Relay
- Sensitive Polarized Relay
- Static Integrator

When $|I_A| - |I_B|$ exceeds the threshold value, the stage acts and the relay picks-up. This method obviously applies to scalar measurement, such as impedance or current differential relaying. To measure a component such as reactance or to obtain the offset current characteristic used in AC pilot wire relaying, it is necessary not only to rectify one input but also to compare it with the value of the other input at a particular moment in the cycle, as shown in Fig. 3.2-24.

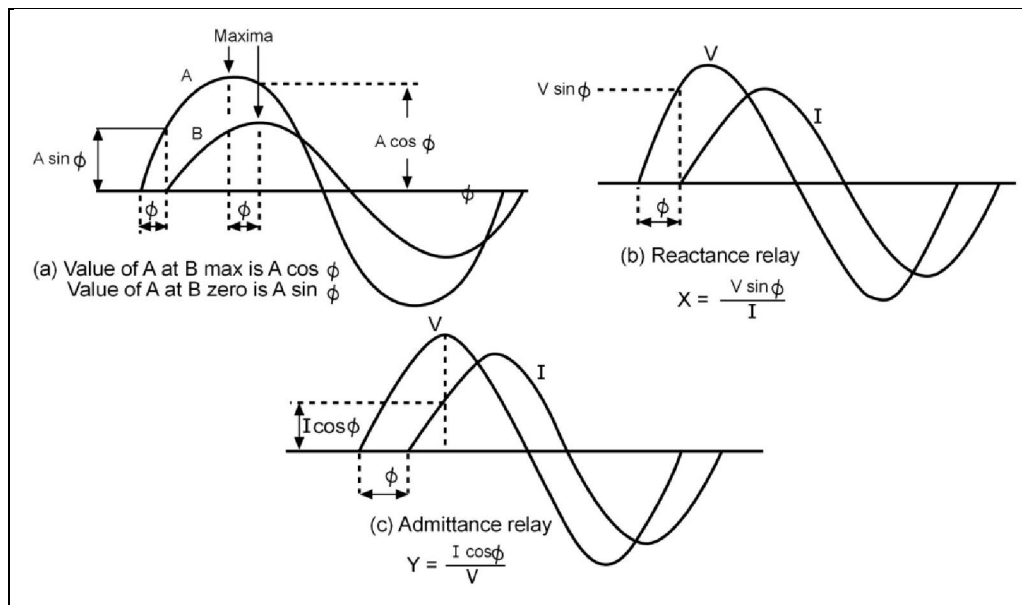


Fig. 3.2-34 Instantaneous Measurement of Complex Impedance

For instance, in a reactance relay, the comparator is made operative only during a pulse at the moment of current zero. In Fig. 3.2-35, if A is potential and B is current, the potential is $V \sin \phi$ at the moment of current zero and, if this instantaneous value of potential is compared with the rectified current (KI), the comparator operates when $V \sin \phi < KI$ or when $X < K$.

If a mho characteristic has been obtained by comparing the rectified potential KV with the instantaneous value of the current $I \cos (\phi - \theta)$ at the instant of voltage peak. The relay operates when $I \cos (\phi - \theta) > KV$ (when $Y \cos (\phi - \theta) > K$), as shown in Fig. 3.2-36.

PHASE COMPARATORS

Phase comparators compare the two or more input quantities, vectorially. The phase comparators recognize the vector relationship between the inputs in magnitude and phase. A vector \bar{A} has magnitude $|A|$ and phase angle, say ϕ .

The two types of phase comparators are:

1. Phase comparator that recognizes only the phase angle between input waveforms. If ϕ is angle between vectors \bar{A} and \bar{B} , the output of phase comparator depends on angle ϕ and the relay responds to the phase angle ϕ between the two inputs.
2. Phase comparator that recognizes the vector product (or division) between two or more input quantities. Thus a phase comparator has output $\bar{A} \cdot \bar{B}$ or \bar{A}/\bar{B} .

COINCIDENCE COMPARISON CIRCUITS

Fig. 3.2-35 shows a phase comparator circuit. The square wave output from each polarity detector is compared in the coincidence detector. The detector will only provide an output signal when both incoming signals are positive or negative. There is no output when they are of different polarity. The output is a series of DC pulses with the time period of each pulse depending upon the phase angle between the two inputs.

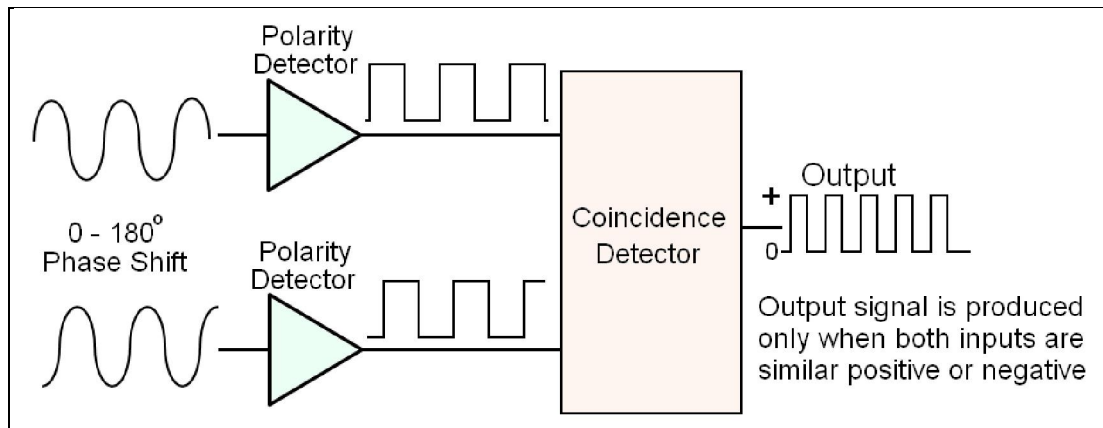


Fig. 3.2-35 Coincidence Comparator (Inputs positive or negative)

The output is constantly high when the input signals are in phase, as shown in Fig. 3.2-36 and is constantly low when the input signals are 180° out of phase, Fig. 3.2-37.

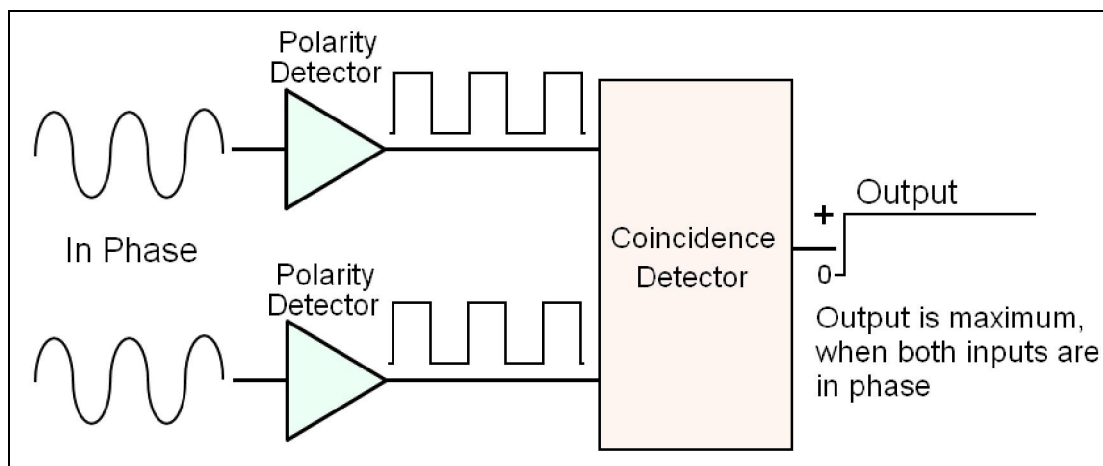


Fig. 3.2-36 Coincidence Comparator (Inputs in Phase)

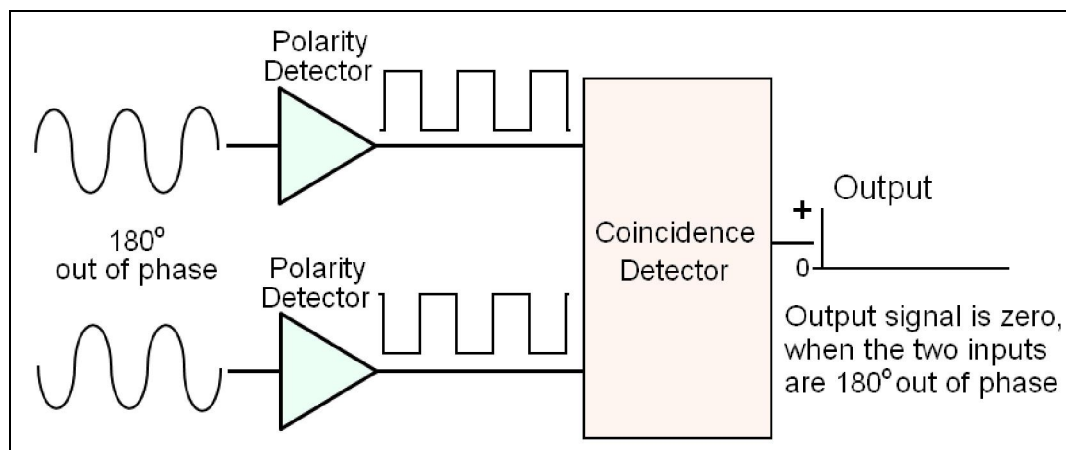


Fig. 3.2-37 Coincidence Comparator (Inputs 180° out of Phase)

SPIKE AND BLOCK COINCIDENCE COMPARATOR

As shown in Fig. 3.2-38, the sinusoidal inputs A and B applied to pulse shaping circuits are converted into spikes and rectangular wave, respectively. The spikes and rectangular wave are applied to an AND gate. The AND gate gives output when both the rectangular block and the spike coincide. The converted pulses are shown in Fig. 3.2-39.

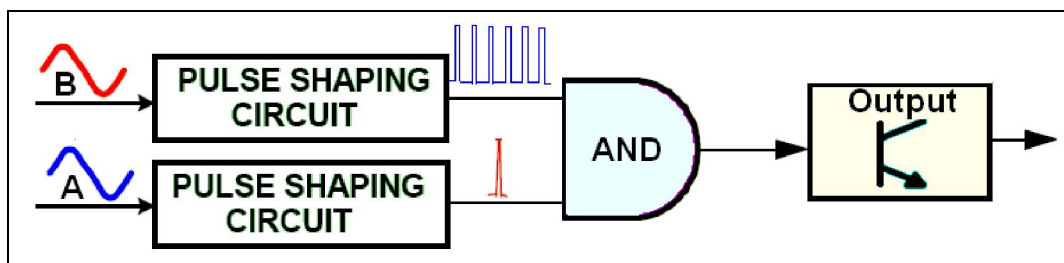


Fig. 3.2-38 Coincidence Phase Comparator Block Diagram

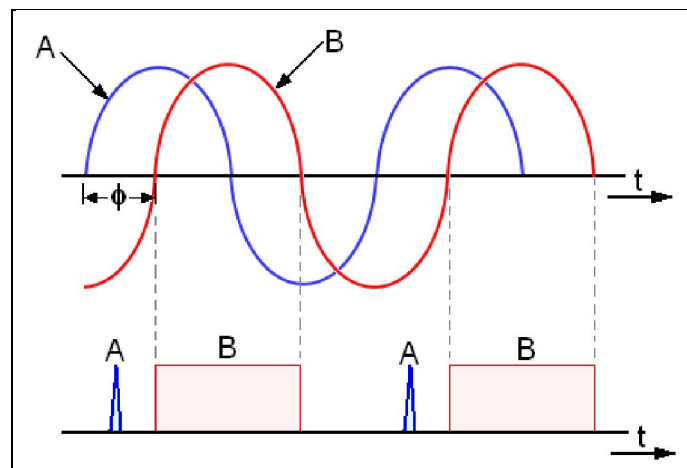


Fig. 3.2-39 Coincidence Phase Comparator Waveforms

PHASE COMPARATOR WITH PHASE SPLITTING TECHNIQUE

Fig. 3.2-40 illustrates this method in which both the inputs A and B are split into two components A, $A \angle 45^\circ$ and B, $B \angle 45^\circ$. Thus totally four input signals are received by the comparator. The inputs are simultaneously positive or negative. The coincidence of all four signals is possible, when the phase angle ϕ between A and B satisfies the condition: $90^\circ > \phi^\circ > -90^\circ$.

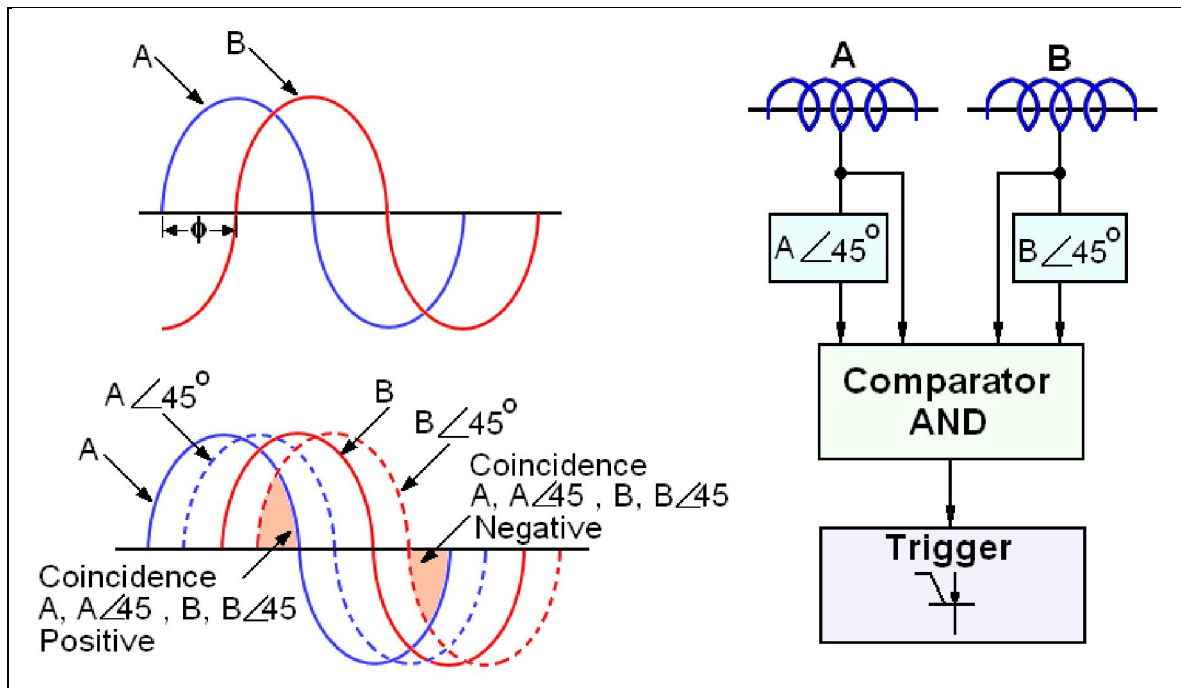


Fig. 3.2-40 Coincidence Phase Comparator with Phase Splitting Technique

BLOCK-TO-BLOCK PHASE COMPARATOR

The Block-to-Block Phase Comparator uses the Zero-Crossing Detector principle to generate square waves. Additional logic circuitry provides an output if the Operate quantity leads the polarizing quantity. One half of the circuit of a Block-to-Block comparator, as shown in Fig. 3.2-41, makes the comparison during the positive half cycles and a similar circuit makes the comparison during the negative half cycles. The input diode arrays D_A and D_B limit the input voltages to 1.4Vp-p for the outputs of the transformers T1 and T2 to be approximately 12V.

For the operating condition shown in Fig. 3.2-41, the leading Operate input makes the base of Q_1 positive before the polarizing input can make Q_3 positive. The transistor Q_1 turns on first, which turns on Q_2 . Since SCR Q_5 has not been gated, it is in the block-state, permitting an output through Q_2 , R_8 , and the output diode. Q_2 turns on reverse-biasing D_3 through D_4 preventing the flow of base current to keep Q_4 off, as otherwise would occur as the lagging polarizing input becomes positive to turn on Q_3 .

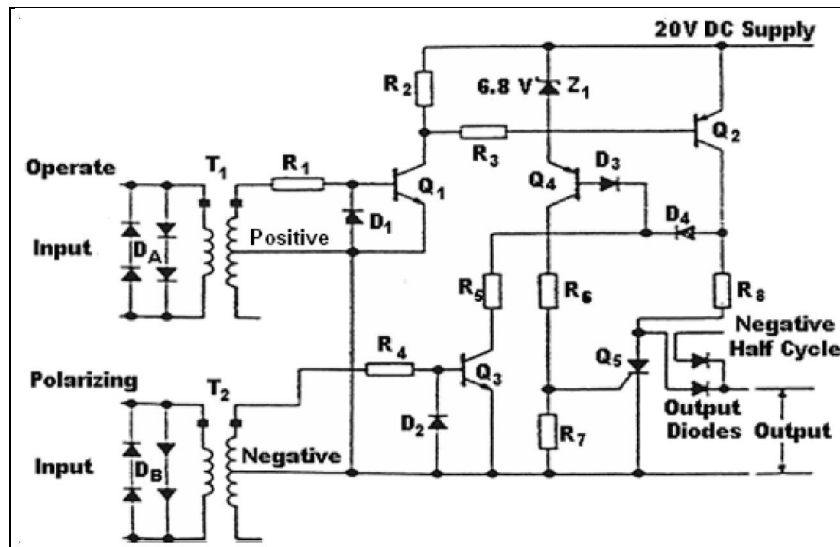


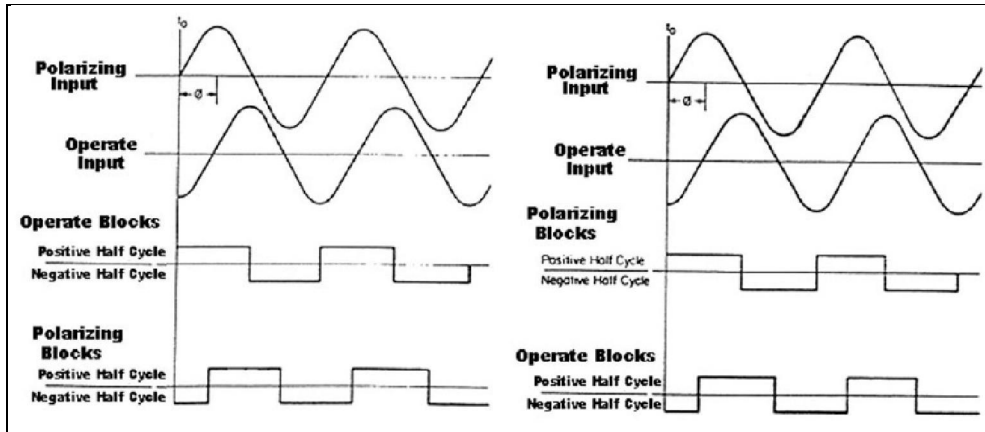
Fig. 3.2-41 Block-to-Block Phase Comparator

Since Q_4 cannot turn on, a half cycle of output occurs. Similarly, during the negative half cycle, leading Operate input provides an output in the other half of the circuit, which connects through its negative half cycle diode to the output.

If however, the polarizing input leads the operate input, as shown in Fig. 3.2-42, the base of Q_3 becomes positive before the base of Q_1 , turning on Q_3 first and then Q_4 . The current flowing through Z_1 , Q_4 , R_6 , and R_7 produces a voltage drop across R_7 to gate SCR Q_5 causing it to conduct and pull the output to negative (low). As the lagging Operate input becomes positive, it turns Q_1 and Q_2 on and since Q_5 is conducting, the current through Q_2 and R_8 is shunted to negative bus.

The Operate input that remains when the polarizing half cycle is completed, cannot produce an output because Q_5 continues to conduct. The polarity of the square waves is the same as that of the generating quantity during corresponding half cycles. The two possible Phase relationships for the Operate condition are shown in Fig. 3.2-42 (a) and (b). An output is obtained if the Operate input leads the polarizing input by 0-180°.

Conversely, no output (Restraint) occurs if the operate input lags the polarizing input by 0-180°, as shown in Fig. 3.2-42. Half cycle square waves are generated at each zero crossing of the respective input quantities.



(a) Operate Input leading

(b) Operate Input lagging

Polarizing Input by 0-180°

Polarizing Input by 0-180°

Fig. 3.2-42 Block-to-Block Phase Comparator Waveforms

PHASE COMPARATOR LOGIC UNITS

A Phase Comparator circuit utilizing digital integrated circuit logic is shown in Fig. 3.2-43. The two Exclusive-OR (XOR) gates (=1) A and C receive as square wave signal having the same zero crossing points as the input signals. The output signals from the XOR gates A and C are inverted by the PNP and NPN transistors at B and D, respectively. The two signals at B and D are compared by the NAND gate, which gives an output logic (1=Restrained) when the square wave inputs are out of phase and no output (0=Operate) when they are in phase. The AC input signal waveforms at the inputs of U1 and U2 amplifiers are converted to square waves with output swinging to $\pm V$ amplitude at X and Y. With no input signal, the X and Y outputs assume -V (0V) logic levels to U3, 4 XOR input terminals, so that all cross-coupled inputs are also 0V, resulting both outputs A and C at low logic (0).

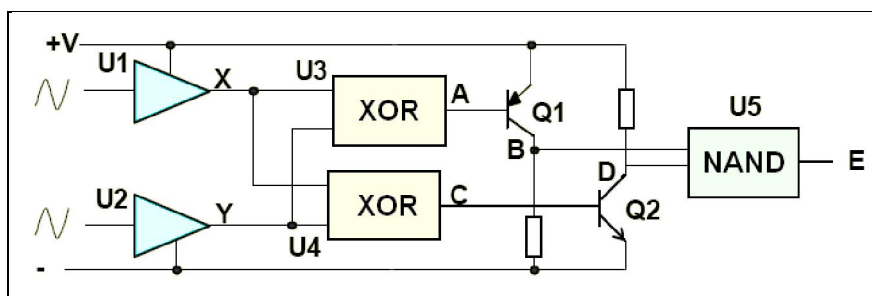


Fig. 3.2-43 Phase Comparator Logic Unit

With both outputs A and C at low logic (0), Q1 is in saturation and Q2 is cut-off, applying high logic (1) to both inputs of U5 NAND gate at B and D giving the output E low logic level (0) indicating in-phase signals at the inputs of the logic unit. These signal for condition 4 comply with the truth table in Table 3.2-1.

Fig. 3.2-44 shows the Input/ Output waveforms that correspond to the truth table below meeting all the logic requirements of the circuit in Fig. 3.2-43. Similarly, the other conditions 1, 2, and 3 in the waveform can be verified by the truth table.

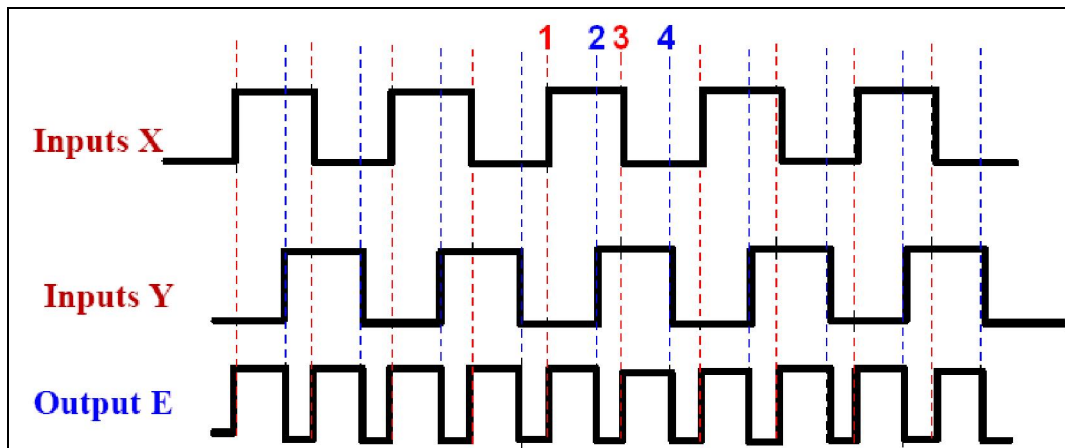


Fig. 3.2-44 Phase Comparator Logic Unit Waveforms

EXCLUSIVE OR			NAND		
X	Y	A or C	B	D	E
0	0	0	0	0	1
0	1	1	0	1	1
1	0	1	1	0	1
1	1	0	1	1	0

CONDITION	X	Y	A	B	C	D	E			RESULT
1	1	0	1	0	1	0	1			Restrain
2	1	1	0	1	0	1	0			Operate
3	0	1	1	0	1	0	1			Restrain
4	0	0	0	1	0	1	0			Operate

Table 3.2-1 Phase Comparator Logic Unit Truth Table

PERIOD OF COINCIDENCE MEASUREMENT

DIRECT PHASE COMPARISON

As shown in Fig. 3.2-45a, one input is converted into square wave (ii) and the other into a spike (iii). The spike and block signals are then fed through an AND gate. If the signals are coincident at any time, the two inputs must be within $\pm 90^\circ$. The output trips when the rectified pulse from one input is coincident with the rectified block from the other input. The squaring of one input means first limiting it and then amplifying it to form a rectangular wave or block in phase with the original sine wave. The spike is produced either by a peaking transformer, as shown in Fig. 3.2-45a (i), by a capacitor charge/discharge circuit, as shown in Fig. 3.2-45b or by squaring the wave with diodes and feeding it through a transformer, as shown in Fig. 3.2-45c.

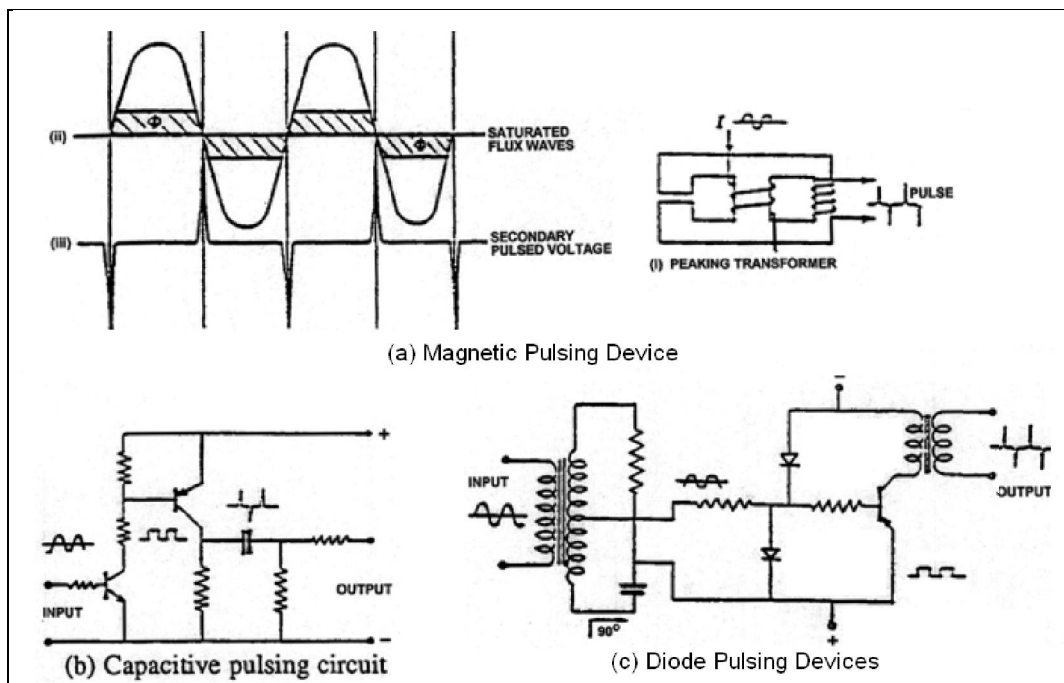


Fig. 3.2-45 Pulsing Devices

Since all these circuits produce pulses as the wave crosses the zero reference, the input wave must be shifted 90° before pulsing in order to make it occur at the peak of the wave. This shift makes it a sine output device. In other words, the output of a phase comparator is inherently $\cos(\phi - \theta)$ where θ is 0° . In the spike and block comparator,

$\theta = 90^\circ$ and the output is $\cos(\theta - \pi/2) = \sin \phi$ and the relay operates when $180^\circ > \phi > 0^\circ$. The spike is always produced at the zero value and then may be shifted in phase as required. A pulse-stretching circuit, as shown in Fig. 3.2-47, makes the output signal last long enough to trip the breaker. This method enables an instantaneous output relay to be used and permits tripping in less than half a cycle. Like all instantaneous measurements, it may be affected by harmonics and spurious spikes caused by external interference that can be minimized if the circuit is adequately shielded.

Fig. 3.2-46 shows how the input signal duration can be increased from the original spike width of about 5° to a period long enough to trip a breaker. These circuits operate only during one half cycle. By duplicating the circuit for the other half-wave polarity, the operating time can be reduced to less than half a cycle.

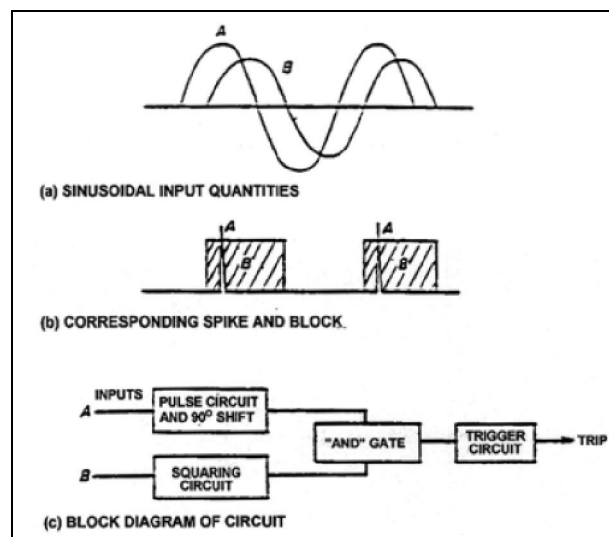


Fig. 3.2-46 Direct Phase Comparators

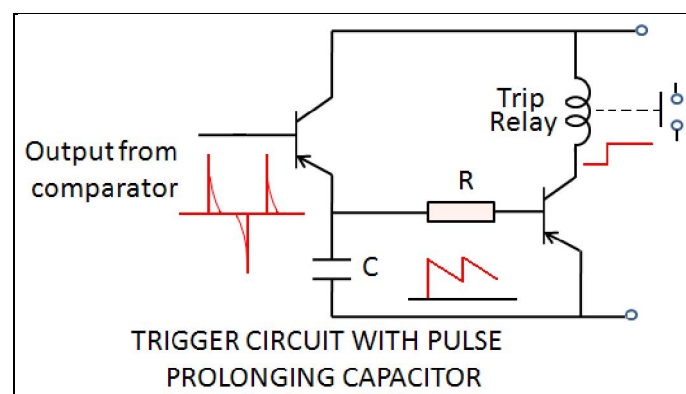


Fig. 3.2-47 Direct Phase Comparators (cont'd)

HYBRID COMPARATORS

Hybrid (mixed version) comparator compares both magnitude and phase of the input quantities, as shown in Fig. 3.2-48. The inputs are applied to a phase comparator. The output of phase comparator is applied to the Amplitude Comparator. The output is available at the level detector. The static impedance relays, which compare V and I are generally hybrid comparators. Variety of impedance diagrams (rectangular elliptical) are possible with Hybrid Comparators.

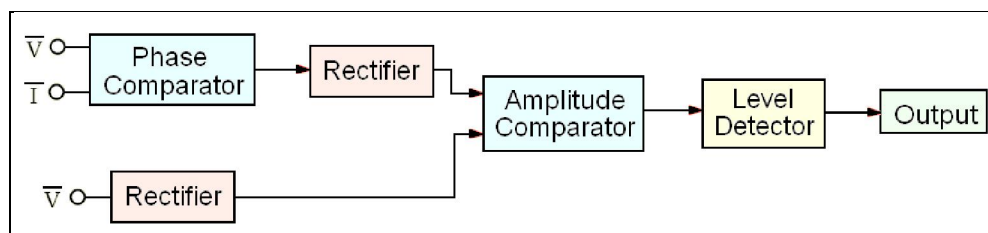


Fig. 3.2-48 Hybrid Comparator used in Distance Relay

ZENER DIODE PHASE COMPARATORS

The two types of zener diode Phase comparators are:

- Coincidence Comparator
- Non-Coincidence Comparator

ZENER DIODE COINCIDENCE PHASE COMPARATOR

Fig. 3.2-49(a) shows the Zener Diode coincidence comparator. This is a cosine type, two input phase comparator delivering a pulse during the positive coincidence period of two sinusoidal inputs to a pulse duration detector. The pulse duration detector can be a telephone type relay, which operates if the pulse duration exceeds 4.15ms (90° duration) for a 60Hz system. The amplitude of the output pulse is equal to only half the zener voltage due to the potential divider arrangement. Hence a very sensitive output relay is needed. The Thevenin equivalent circuit is shown in Fig. 3.2-49(b) for the positive coincidence period. During the coincidence period, ZD2 is conducting with negligible voltage drop across it while ZD1 is reverse biased with zener voltage

(V_Z) across it. If the telephone relay has negligible resistance and an inductance of L Henries with N turns.

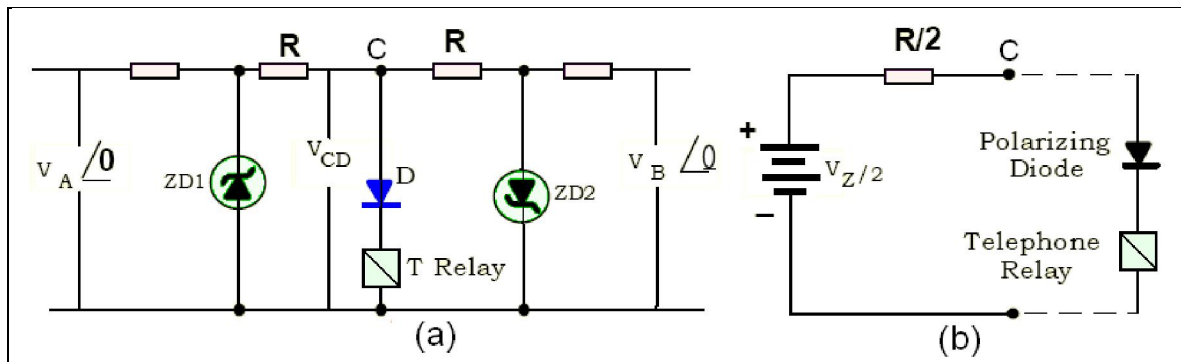


Fig. 3.2-49 Zener Diode Coincidence Comparator

ZENER DIODE NON-COINCIDENCE PHASE COMPARATOR

Fig. 3.2-50(a) shows the non-coincidence phase comparator circuit and Fig. 3.2-50(b) its Thevenin equivalent circuit. Voltage is developed across the telephone relay only during the non-coincidence period when $ZD1$ is reverse biased and $ZD2$ is forward biased. If the relay picks up at the same current as in the previous case, the following values are obtained.

External resistance = $R \Omega$

Relay inductance = $2L$ Henries

The pick-up mmf is, therefore, $\sqrt{2}$ times that of the previous case and a more robust relay can be used for the same loading on the voltage.

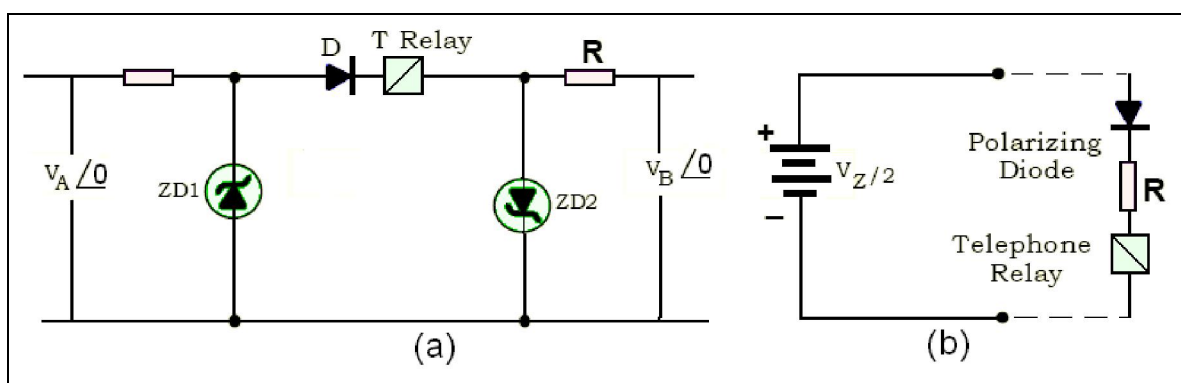


Fig. 3.2-50 Zener Diode Non-Coincidence Comparator

Another circuit of polarity detector is shown in Fig 3.2-51. It compares the polarity of an AC waveform with another reference AC waveform. Any change happens in polarity between them can be detected from the NAND output.

Note that the operational amplifier is used as a simple comparator to change AC wave to square wave.

When the two input waves are in phase; the signals at point X & Y are both square waves and in phase, resulting that the output of the two transistors Q_1 & Q_2 at points B & D both are 1 then the output of the NAND gate is 0.

When the two input waves are not in phase; the signals at point X & Y are both square waves but not in phase, resulting that the output of the two transistors Q_1 & Q_2 at points B & D are =1& 0; then the output of the NAND gate =1.

So, when the NAND gate produces 1 at point E; then the polarity of the two input waves is not in agreement but producing 0 at point E means the two inputs are in agreement with the phase angle.

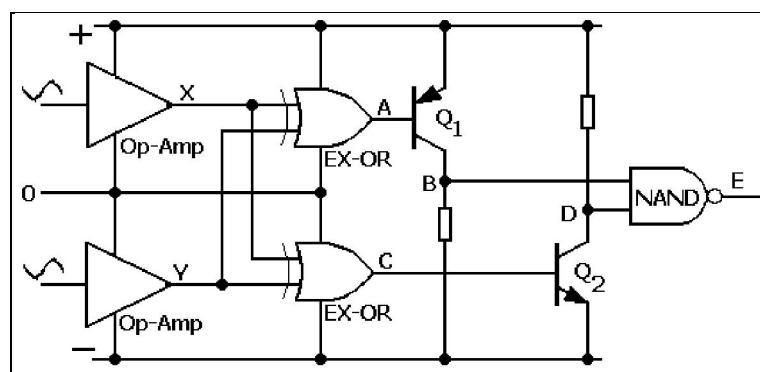


Fig. 3.2-51 Phase comparator circuit using logic units

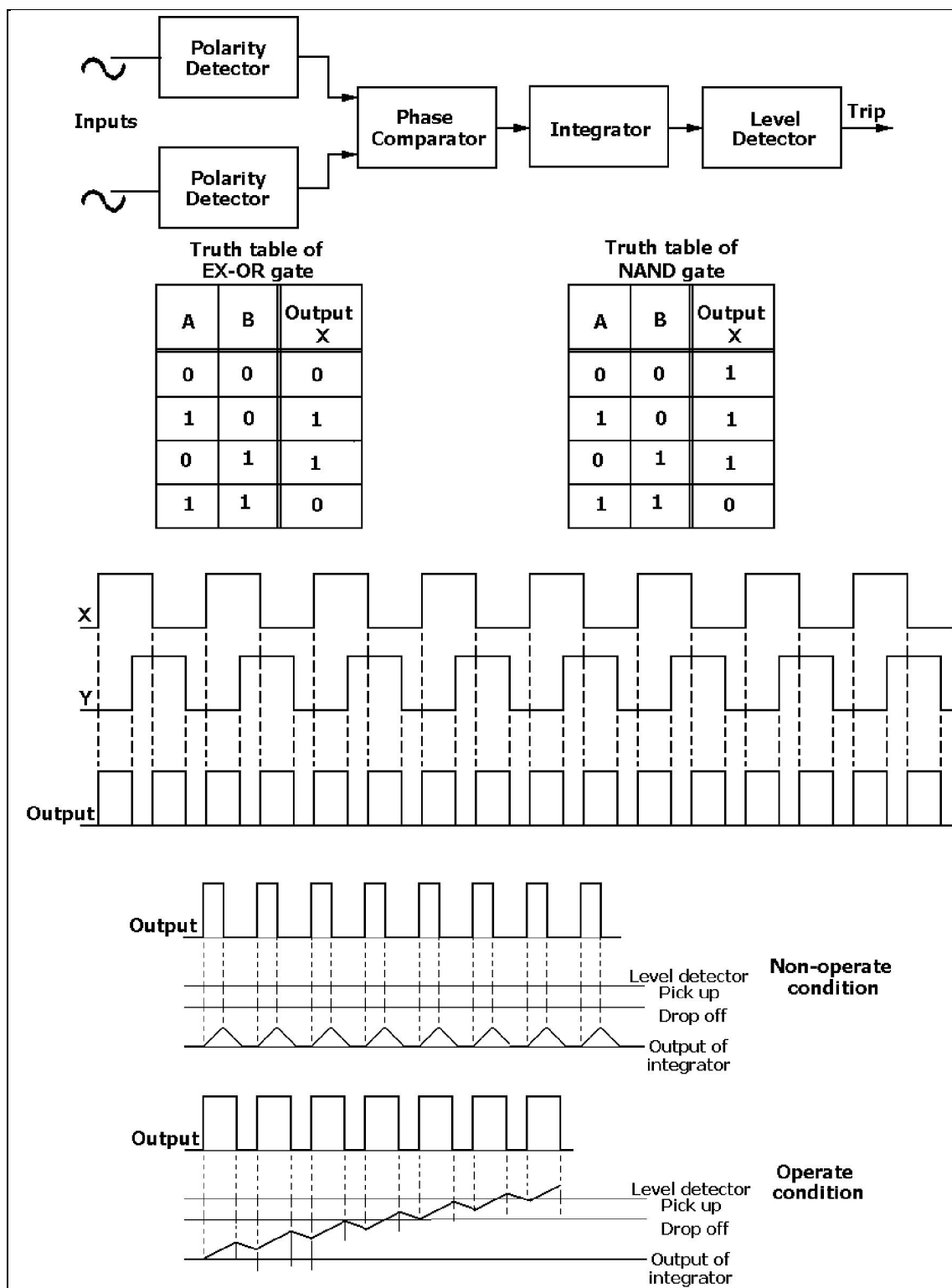


Fig. 3.2-52 Operation of Phase detector

A complete phase comparator block diagram, the truth tables for the used logic gates and the waveforms are shown in Fig 3.2-52.

PHASE SHIFT CIRCUITS

Phase shift circuits are used to compare the amplitude of vectorial quantities, especially in the applications of directionality and negative sequence. Each phase shift circuit responses for one of the four quadrants. Therefore, the selection for the phase shift circuit is according to the quadrant to operate in.

Fig. 3.2-53 and 54 show phase shift circuits for the 2nd and 3rd quadrant respectively.

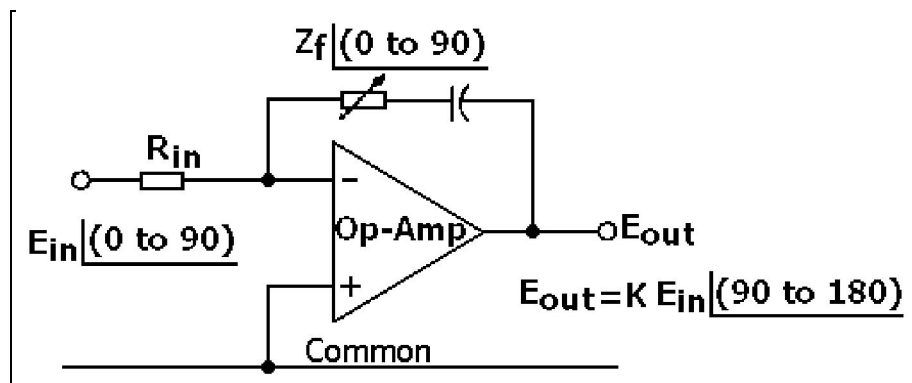


Fig. 3.2-53 Phase Shift Angle for Voltage Signal in the 2nd Quadrant

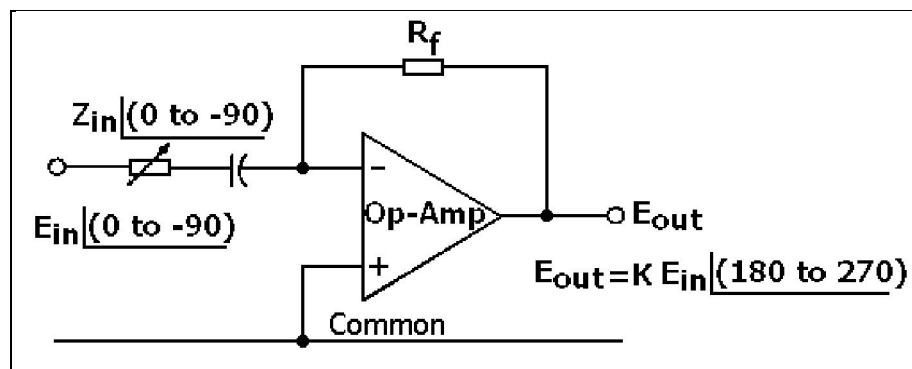


Fig. 3.2-54 Phase Shift Angle for Voltage Signal in the 3rd Quadrant

ZERO CROSSING DETECTOR

Zero crossing detector circuit is used to determine if the sign of the input wave change from positive to negative or the opposite; and generate pulse for each change. The generated pulse is repeated either 180° or 360°. A typical zero crossing detector circuit is shown in Fig 3.2-55. It is used mainly with the input current or voltage secondary of

CTs or VTs to know if the wave was starting to begin estimating some results related to polarity, time lagging, and directionality.

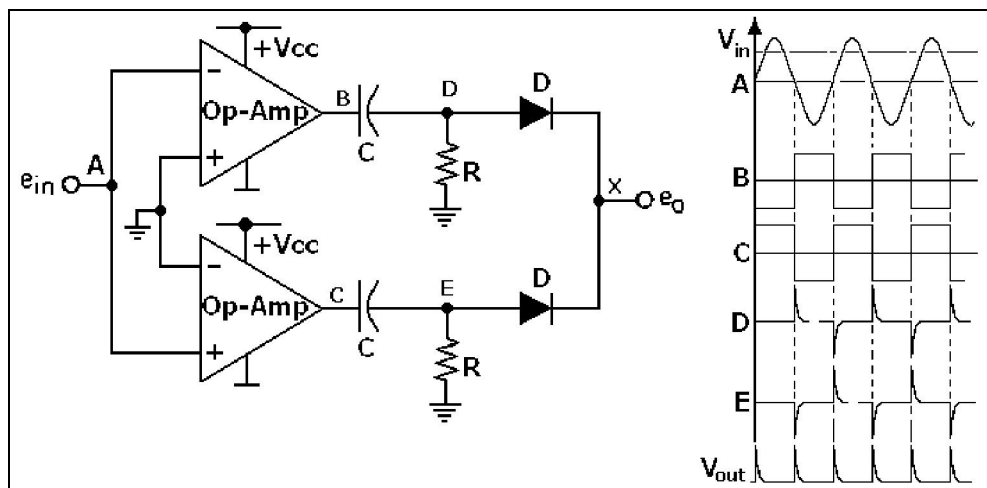


Fig. 3.2-25 Zero crossing detector

SUMMARY FOR COMPARATOR CIRCUITS

- A Comparator in part of relay receives two or more inputs to be compared and gives an output based on their comparison ($A > B$, $A < B$, or $A = B$).
- In an Amplitude Comparator, the two incoming signals are rectified and connected in opposition, one to trip and one to restrain, resulting in a DC signal equal to the difference ($I_A - I_B$).
- The phase comparators recognize the vector relationship between two or more inputs in magnitude and phase.
- In a Phase comparator, the relay responds to the phase angle ϕ between the two inputs.
- The two types of zener diode Phase comparators are:
Coincidence Comparator
Non-Coincidence Comparator
- In Zener diode Coincidence comparator, the two inputs deliver an output pulse during the positive or negative coincidence period of two sinusoidal inputs to a pulse duration detector relay.

- _____
- _____
- _____



- a) True b) False

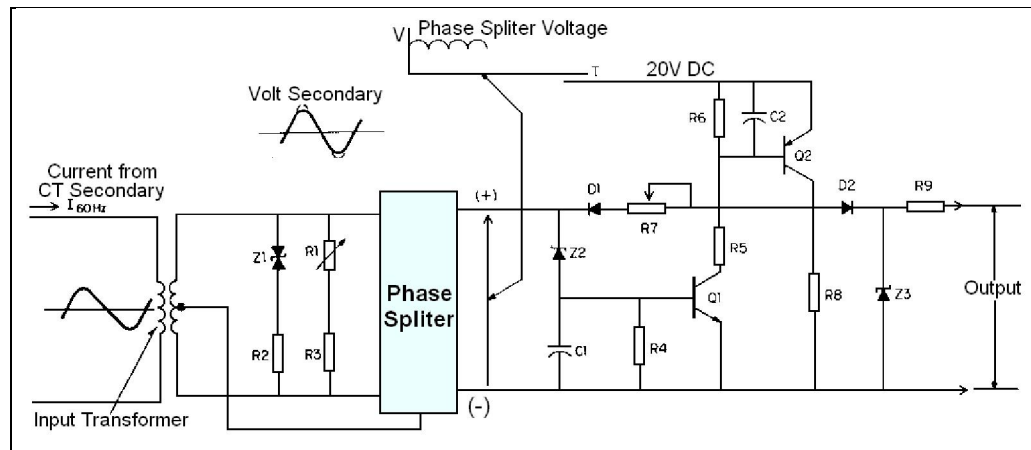


Fig. 3.2-30 Magnitude Comparator DC Level Detector
in Instantaneous O/C Unit

5. In the given input/output waveforms for Direct Comparison of 6-Phase-Split Inputs to Amplitude Comparator in Fig. 3.2-33, the peak of the operating signal (unfiltered) must not exceed the restraint level for operation of the relay.

a) True

b) False

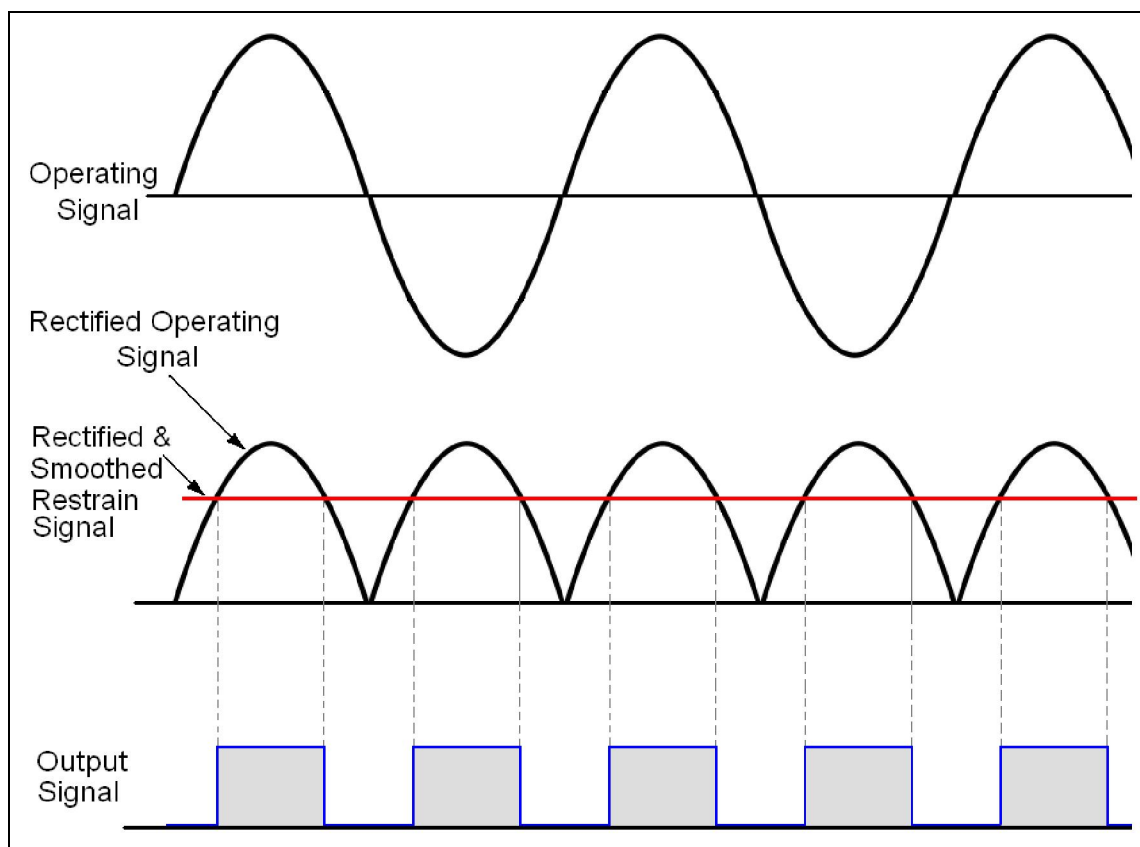


Fig. 3.2-33 Amplitude Comparator Output for Direct Comparison

6. In a Phase comparator, the relay responds to the _____ between the two inputs.
 - a) Phase angle
 - b) Amplitude
 - c) Phase angle and Amplitude
 - d) All of above
7. A Phase comparator can recognize the _____, _____ or _____ between two or more input quantities.
8. The coincidence detector in a Phase Comparator only provides an output signal when both incoming signals are _____:
 - a) Positive
 - b) negative
 - c) same polarity
 - d) All of above
9. The output of a coincidence detector is constantly _____ when the input signals are in phase and is constantly _____ when the input signals are 180° out of phase.
10. In Fig. 3.2-41 for the Block-to-Block Phase Comparator:
 - i) One half of the circuit makes the comparison during the positive half cycles and the other half of the circuit makes the comparison during the negative half cycles.
 - a) True
 - b) False
 - ii) The input diode arrays DA and DB limit the input voltages to _____ for the outputs of the transformers T1 and T2 to be approximately 12V.
 - iii) The leading Operate input makes the base of _____ positive before the polarizing input can make _____ positive. The transistor _____ turns on first, which turns on _____. Since SCR _____ has not been gated, it is in the _____, permitting an output through _____, _____, and the output diode.

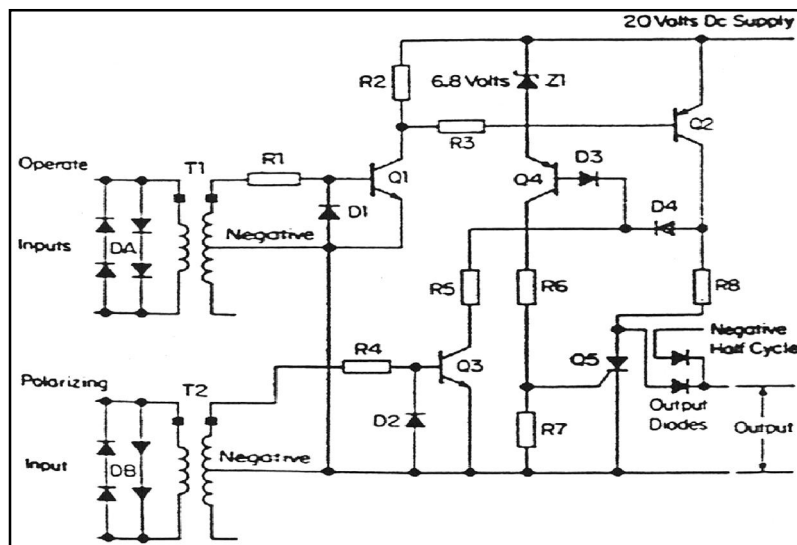


Fig. 3.2-41 Block-to-Block Phase Comparator

11. Given the schematic diagram of a Phase Comparator Logic Unit in Fig. 3.2-43, with both outputs A and C at low logic (0), Q1 is in _____ and Q2 is _____, applying _____ logic to both inputs of U5 NAND gate at B and D giving the output E _____ logic level indicating in-phase signals at the inputs of the logic unit.

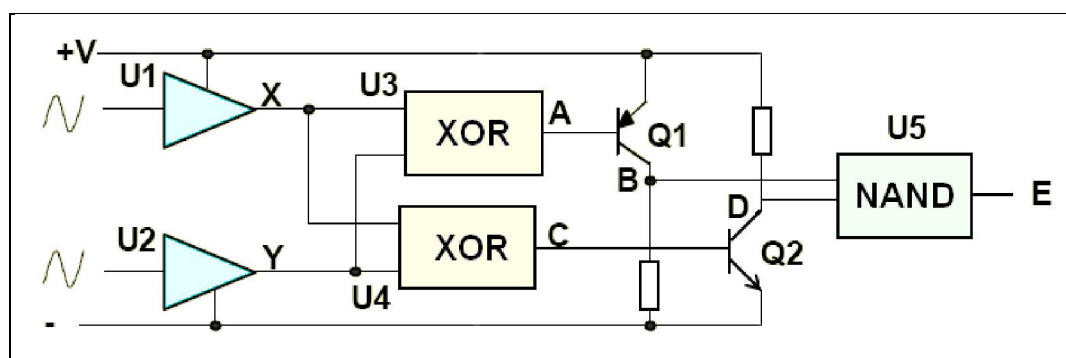


Fig. 3.2-43 Phase Comparator Logic Unit

- 12 In Fig. 3.2-49 for the Zener Diode coincidence comparator:
- The two inputs deliver an output pulse during the positive or negative coincidence period of two sinusoidal inputs to a pulse duration detector relay.
 - True
 - False
 - The amplitude of the output pulse is equal to _____ the zener voltage due to the potential divider arrangement.

- 275



TASK 3.2-1

DC-DC CONVERTER

OBJECTIVE

Upon completion of this task, the trainee will be able to demonstrate the operation of a DC-DC converter.

TOOLS, MATERIALS & REQUIREMENTS

- | | |
|--------------------------------------|---------------------------------------|
| 1- Power source, 0-12V DC | 1- Milli ammeter, 0-100 mA DC |
| 1- Silicon diode D ₁ | 1- AVO/DVM meter |
| 2- Two transistors, NPN 2N2219A | 1- Oscilloscope |
| 1- Coupling Capacitor, 0.022 μ F | 1- Transformer |
| 2- Resistors, 10 k Ω , 1W | 1- Electrolytic Capacitor, 50 μ F |
| | 1- Resistor, 22 k Ω , 1W |

PROCEDURE

1. Examine the equipment, tools and components for good condition.
2. Connect the circuit as shown in Fig. 1-1.

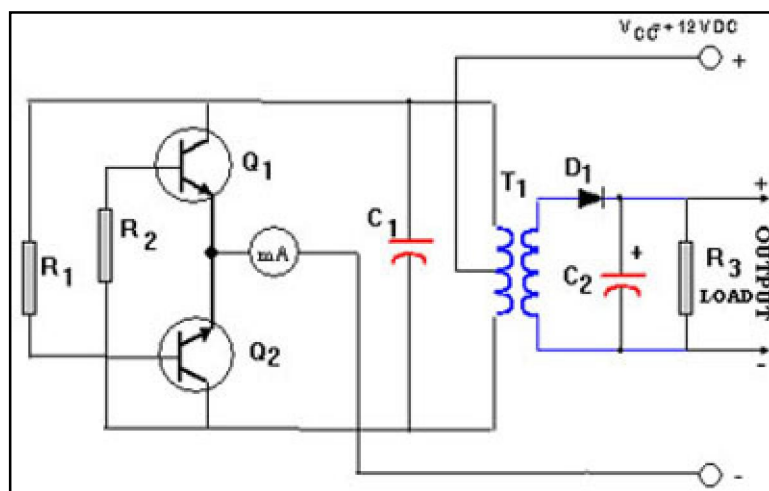


Fig. 1-1 DC Converter Circuit

NOTE

Diode D_1 is a half wave rectifier. C_2 is filter capacitor. Resistor R_3 is the minimum load resistor when the output is open circuit.

3. Adjust the DC power supply to 12V DC and measure the converter DC current drain indicated on the milli ammeter in the emitter circuit. Record the value (I_C).
4. Adjust oscilloscope with assistance of the instructor and monitor the waveforms across the collector and emitter terminals, peak-to-peak primary and secondary voltages across the transformer T_1 . Draw the waveforms V_{C1} and V_{C2} with respect to emitter terminal in Fig. 1-2. Determine:

Phase angle of V_{C1} and V_{C2} waveforms. $\theta = \underline{\hspace{2cm}}^\circ$

Peak-to-peak value of primary voltage E_p . $E_p = \underline{\hspace{2cm}} V_{p-p}$

Peak-to-peak value of secondary voltage E_s . $E_s = \underline{\hspace{2cm}} V_{p-p}$

Is there any saturation or cutoff observed on the waveforms, why?

V_{C1} : Saturation: $\underline{\hspace{2cm}}$ Cutoff: $\underline{\hspace{2cm}}$

V_{C2} : Saturation: $\underline{\hspace{2cm}}$ Cutoff: $\underline{\hspace{2cm}}$

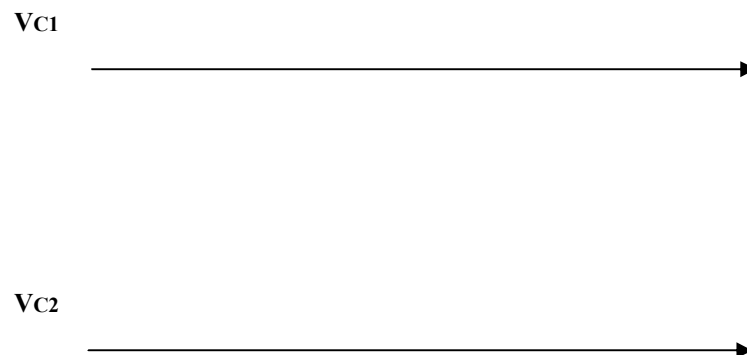


Fig. 1-2 DC-DC Converter Waveforms

5. Measure the period (**T**) of one complete cycle and record this value.

$$T = \underline{\hspace{2cm}} \text{ ms}$$

6. Measure the frequency of oscillation (**f**).

$$f = \underline{\hspace{2cm}} \text{ Hz}$$

7. Set the AVO/DVM meter to 50V DC range and measure the DC voltage across load resistor **R₃**.

$$V_o = \underline{\hspace{2cm}} \text{ V}$$

8. Demonstrate the operation of the converter to the instructor.

Reduce the power supply voltage to zero volts.

TASK 3.2-2

USING OPERATIONAL AMPLIFIER AS COMPARATOR

OBJECTIVE

Upon completion of this task, the trainee will be able to demonstrate the op-amp as a comparator.

TOOLS, MATERIALS, & REQUIREMENTS

1 - ET-3100 Trainer

1 - 741 op-amp (442-22)

DVM/VOM (multi-meter)

2 – 1k resistors

Oscilloscope

INTRODUCTION

This experiment demonstrates a practical application of the operational amplifier. The comparator application of the op-amp, which we will study, does not require negative feedback. Before experimenting with the comparator, we will measure the input and output resistance of the op-amp.

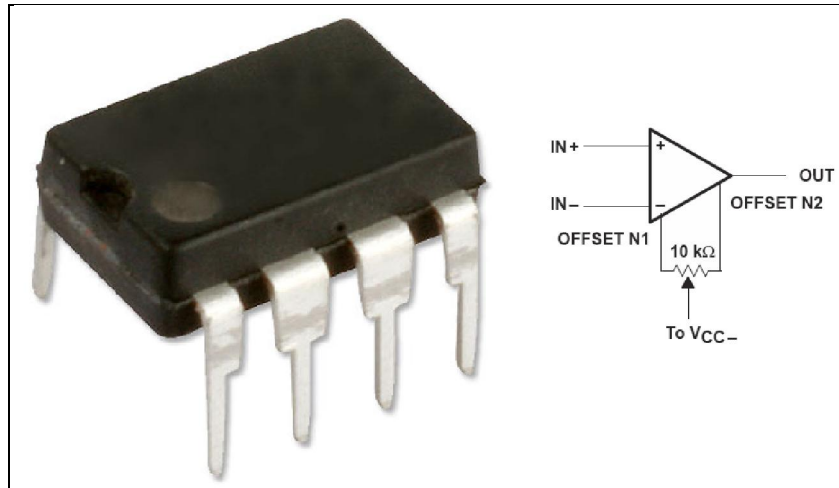


Fig. 2-1 Op-Amp-741 Characteristics

The package outline of 741 op-amp as Dual-in-Line Package (DIP) is shown in Fig. 2-1A, indicating pin 1 orientation. Fig. 2-1B lists the designated pin-outs of the device. Pin 1 identification as well as the pin numbering has been relatively standardized in the electronics industry.

PARAMETER	VALUE
Supply Voltage	$\pm 18\text{V}$
Input Voltage	$\pm 15\text{V}$ (or Supply voltage level, whichever is lower)
Differential Input Voltage	30Vp-p

Table 1-1 Absolute Maximum Ratings for 741 Op-amp

Input Offset Voltage	2mV
Input Offset Current	20nA
Input Resistance	2M
Input Capacitance	1.4pF
Gain	200,000 or 200V/mV
Output Resistance	75Ω
Common Mode Rejection Ratio CMRR)	30,000
Slew Rate	0.5V/μs

Table 1-2 Electrical characteristics of 741 Op-amp

PRECAUTION

If any one of the absolute maximum ratings in Table 1-1 and 1-2 is exceeded, the op-amp may get damaged.

PROCEDURE

1. Construct the circuit shown in Fig. 2-1 for non-inverting comparator. Set the supply voltages to ± 10 volts.

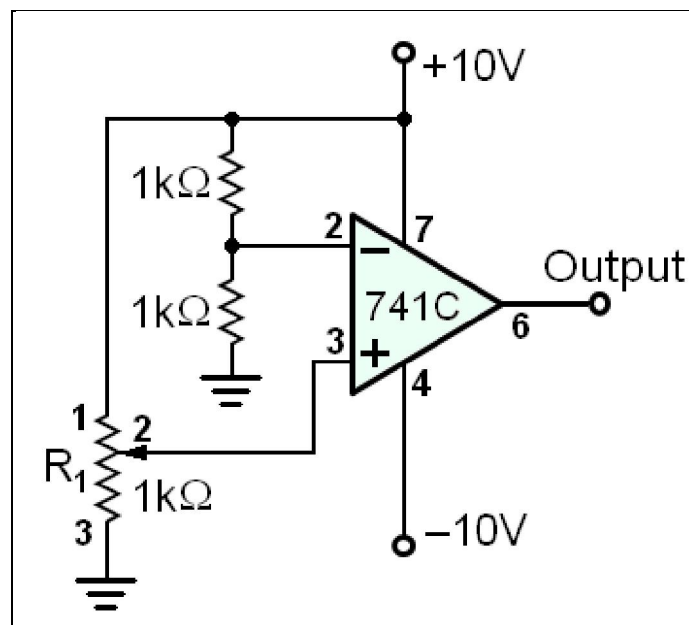


Fig. 2-1 Linear IC Comparator

2. Set the 1K potentiometer fully clockwise. Measure the DC voltage at pin 3 of the op-amp:

V3(non-inv) = _____ volts

3. Measure the DC voltage at the inverting input pin 2 of the op-amp:

V2(inv) = _____ volts ($\approx +5V$)

The voltage at the inverting input pin 2 of the op-amp being positive ($\approx +5V$), the output voltage will be Positive/Negative _____ depending on the DC voltage at pin 3 of the op-amp in Step 2.

4. Measure the DC voltage at pin 6 of the op-amp:

V6(out) = _____ volts

5. Very slowly, turn the 1K potentiometer counterclockwise, while monitoring the output voltage. At some point, the output voltage will suddenly change polarity. Stop turning the potentiometer as soon as you reach this point.
6. With the potentiometer set at this “switch over” point, measure the two input voltages:
 $V_2(\text{inv}) = \underline{\hspace{2cm}}$ volts
 $V_3(\text{non-inv}) = \underline{\hspace{2cm}}$ volts
 Are these two voltages equal? Yes: No:
7. Turn the potentiometer fully counterclockwise. Measure the output voltage at pin 6 of the op-amp: $V_6(\text{out}) = \underline{\hspace{2cm}}$ volts
8. Very slowly turn the potentiometer clockwise as you monitor the output voltage. Again, the output voltage will suddenly switch polarity at some point.
9. With the potentiometer set at this “switch over” point, measure the two input voltages:
 $V_2(\text{inv}) = \underline{\hspace{2cm}}$ volts
 $V_3(\text{non-inv}) = \underline{\hspace{2cm}}$ volts
 Are these two voltages equal? Yes: No:
10. Construct the circuit shown in Fig. 2-2. Adjust the supply voltages to ± 10 volts.
11. Set the Generator RANGE switch to LOW and FREQUENCY to 1kHz.
12. Connect the external trigger input jack of the oscilloscope to the generator SQUARE terminal on the ET-3100. Place the oscilloscope in the external triggering mode. Set the triggering polarity or slope switch to the “+” position. Connect the ground lead of the oscilloscope to one of the GND terminals on the ET-3100. Connect the lead from the vertical input to the SINE terminal of the Generator. Adjust the TIME/cm or horizontal sweep rate on the oscilloscope until a few cycles of the sine wave are visible on the screen.

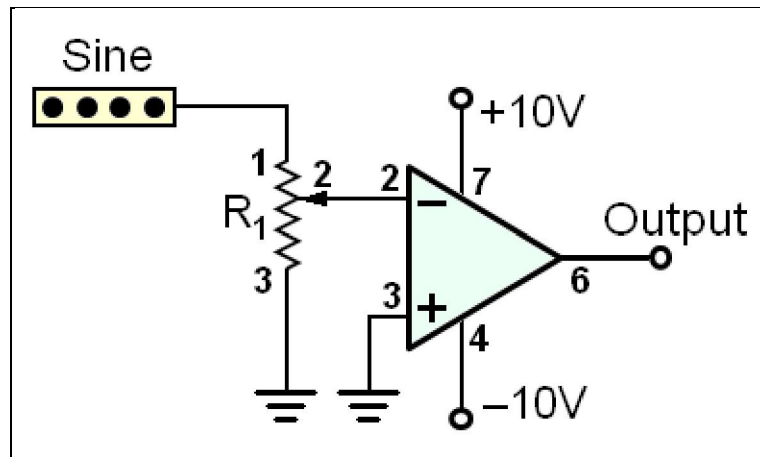
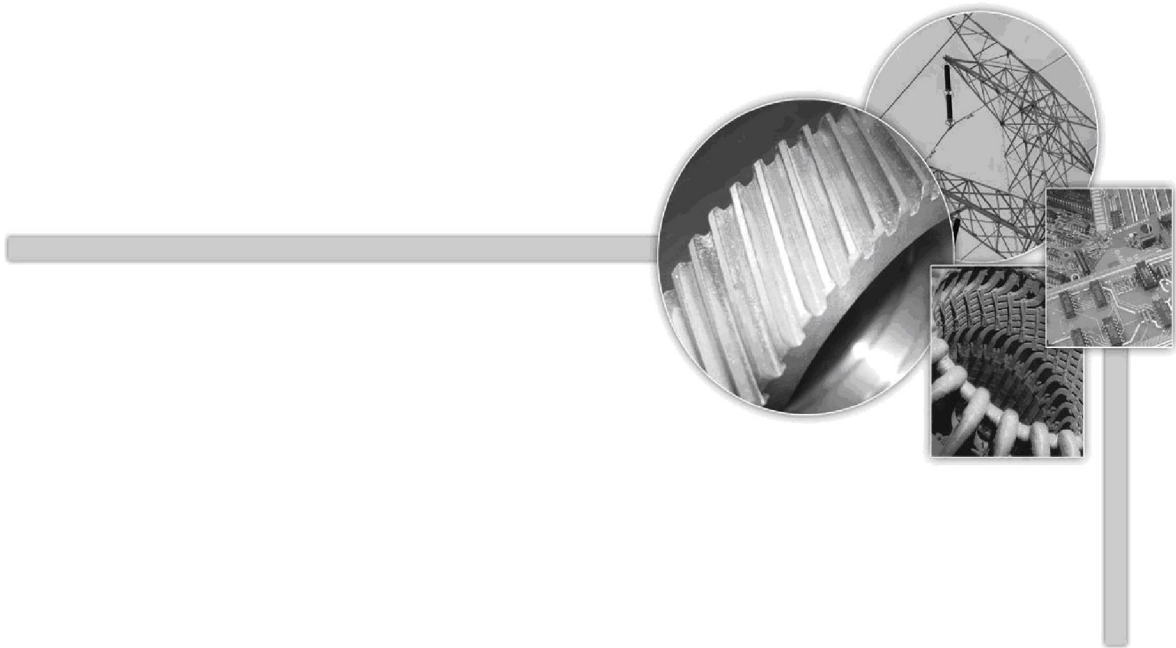


Fig. 2-2 Circuit for Steps 10-14

13. Using the space provided in Fig. 2-3A, draw the first two cycles of the input signal.
14. Move the scope probe to pin 6 of the op-amp. Using the space provided in Fig. 2-3B, draw the first two cycles of the output signal.

	First Cycle	Second Cycle
<div style="text-align: center;"> A Input Signal </div>		
<div style="text-align: center;"> B Output Signal </div>		

Fig. 2-3 Waveforms for Steps 13-14



LESSON 3.3

STATIC RELAY APPLICATIONS

LESSON 3.3

STATIC RELAY APPLICATIONS

OVERVIEW

This lesson lists the functional blocks representing different functions to be performed in a typical Static Relay. The applications of UJT and Thyristors in control circuits relevant to Static Relays are discussed, enhancing troubleshooting techniques.

OBJECTIVES

- Describe the different functional blocks in a typical Static Relay.
- List the three basic functional blocks of an electronic Static Over-Current (O/C) Relay.
- List the advantages of Static Relays.
- List the limitations of Static Relays.
- Analyze the operation and characteristics of discrete transistors as switches or amplifiers.
- Describe the application of SCR in a simplified Circuit Breaker Trip Coil control circuit.
- Analyze the operation and apply troubleshooting concepts in Thyristor application circuits relevant to Static Relays:

INTRODUCTION

A solid-state Protective Relay is divided into the following different functional blocks depending on the electronic application of the devices used:

- Primary wiring from the instrument transformers to the Circuit Breaker **(CB)**.
- Relay Input Network.
- Measurement.
- Auxiliary Functions (Timers and Logic Circuits).
- Output Circuits and Tripping.
- Auxiliary DC Supply.
- Internal Wiring and Connectors.

Most failures occur in the Measurement, Auxiliary Elements and the auxiliary DC Supply circuit of Static Relays. Very rarely, failures have been recorded in Transformers, Tripping and in Internal Wiring. Failures in solid-state equipment can usually be traced to a particular printed circuit board or module with the aid of the manufacturer's test procedures. Replacement of a faulty board or module, which usually has plug-in connectors, enables the equipment to be restored to service with a minimum of delay. Tracing and replacement of faulty components on a Printed Circuit Board (PCB) requires the field related knowledge and equipment with all the necessary drawings, such as Block Diagram, Schematic, Component Board Layout and user manuals. In order to achieve quick restoration of defective equipment, a suitable stock of spare cards and modules should be available.

Fig. 3.3-1 illustrates the essential components in the block diagram of a typical Static Relay. The transducer output of CTs or PTs is rectified in a Rectifier and Filter block. The rectified output is fed to the Measuring Unit consisting of Level Detector and Comparator. The output is initiated when input reaches a certain Setting value. The output of the Measuring Unit is amplified by the Amplifier block and is applied to the Output Circuits initiating the Trip Relay. The Trip Relay incorporates a hinged armature or a miniature polarized moving coil as the output device with a number of contacts for the tripping function.

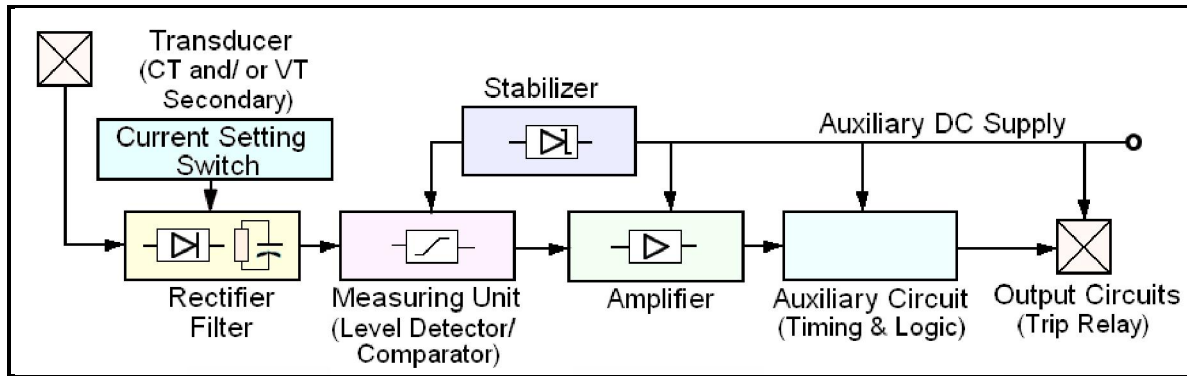


Fig. 3.3-1 Block Diagram of Typical Static Relay

Trip Relays in modern relay units. The pickup of the relay is obtained by a moving element of the relay, whereas static relays have solid-state circuits performing the measurement.

The three basic functional blocks of Static Over-Current (O/C) Relay are:

• Input Circuit:	Main Circuit Breaker (CT), auxiliary CT, Current Setting Switch, Rectifier, and RC-Filter
• Intermediate Stage:	Level Detector and an Amplifier
• Output Circuit:	Tripping Relay

THYRISTOR APPLICATIONS IN STATIC RELAYS

An output device (**Trip Aux. Relay**) for a high-speed protective relay must fulfill three main requirements:

1. High speed operation, less than 2-3ms.
2. Capable to trip Circuit Breakers directly.
3. Maintenance free, large number of operations.

Thyristor (SCR) can fulfill the above requirements but has to be protected by transient protection circuitry for reliable operation, particularly for multi-circuit outputs. An SCR is employed in the output stage of Static Relays, Fig. 3.3-2. The measuring circuit of the relay sends pulses to the gate of the SCR, when the preset condition is reached, SCR is triggered, the battery current flows through the Trip Coil of the Circuit Breaker (CB) in series with the interlock Auxiliary Switch and current limiting

resistor. As the Circuit Breaker opens, the interlock Auxiliary Switch also opens turning the Anode current to 0A and thereby, switching the SCR Off. The diode D_1 protects the SCR from the back EMF of the coil due to reversal of polarity, when de-energized, short-circuiting the reverse polarity voltage across the coil.

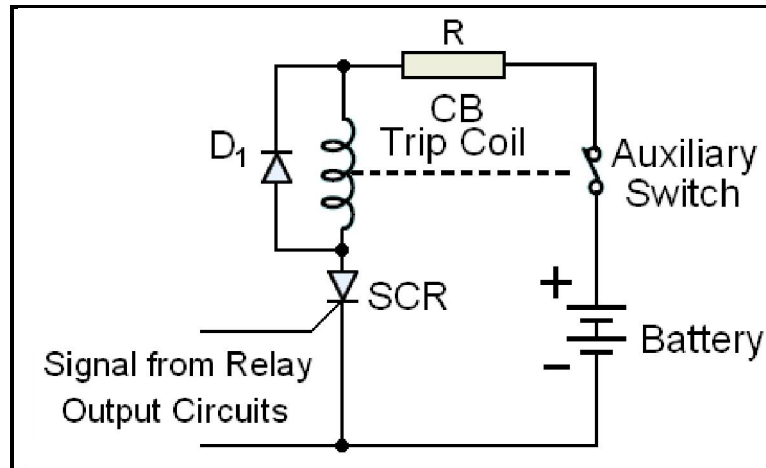


Fig. 3.3-2 SCR Application in CB Tripping

The operation of two types of Trip circuits, as shown in Fig. 4-3 is as follows.

In Fig. 3.3-3(a), the triggering pulse is RC-coupled through capacitor C and resistor R_2 at the output of transistor T where emitter is biased at 0.7V by constant current through diode D and resistor R_3 . The collector voltage of the transistor, when cutoff, charges the capacitor C and the charging current triggers the SCR gate.

The advantage of this circuit is, that there is no restriction on the input pulse width because the differentiated positive trigger pulse appears only when the transistor turns off, dependent on the charging current through the gate of the SCR.

In Fig. 3.3-3(b), trigger pulse is transformer-coupled through a pulse transformer at the output of transistor T. Initially the capacitor C is charged by the power supply and the collector of the PNP transistor is at ground potential, so that the transistor is off. When the negative going pulse is applied between the base and emitter of transistor T, the transistor conducts discharging the capacitor through the pulse transformer and triggering the SCR. The advantage of this circuit is, that there is isolation between input circuit and the output due to AC-coupling through the pulse transformer. The transistor acts as a switch (ON/OFF) in both cases.

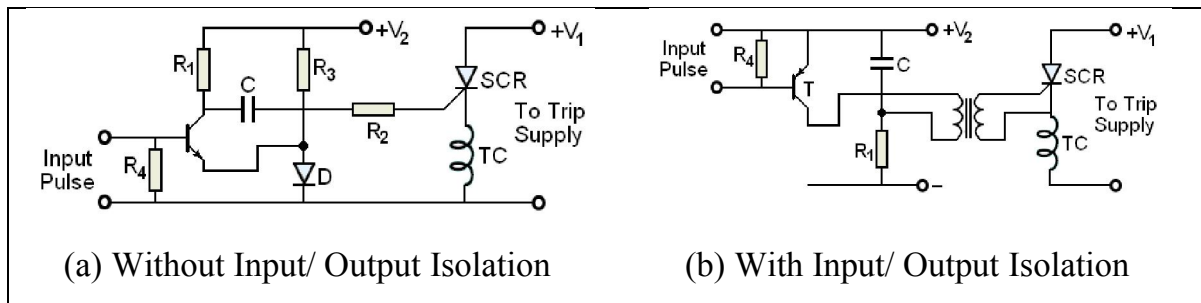


Fig. 3.3-3 CB Tripping Circuits

CIRCUIT BREAKER TRIP COIL INITIATOR

The Circuit Breaker Trip Coil initiator circuit provides power amplification for the Trip Coil and also isolates the control circuitry from the tripping source supply (station battery). Fig. 3.3-4 shows a CB Trip Coil initiator circuit, where the triggering circuit consists of NPN transistor Q_1 , PNP transistor Q_2 , uni-junction transistor Q_3 , and pulse transformer T_1 . Under normal operating conditions, transistors Q_1 and Q_2 are biased off and capacitor C_2 is discharged. Q_1 turns on when the input voltage from the fault-sensing and data processing circuit exceeds 2V. Q_1 then turns on Q_2 acting as constant current source and allowing C_2 to charge through R_6 . When the voltage across C_2 reaches the firing voltage, peak-point value (V_p) of the uni-junction transistor Q_3 , the UJT is triggered and C_2 discharges through transformer T_1 primary.

$$V_p = V_F + \eta V_{BB} \quad \eta = r_{b1}/r_{bb} \quad r_{bb} = r_{b1} + r_{b2}$$

When the discharging voltage across the capacitor C_2 reaches the Valley point voltage (V_v), Q_3 turns off and capacitor C_2 starts charging again. The UJT would output a continuous firing pulse train through transformer T_1 as long as transistor Q_2 is on, provided the input signal is present. The pulses are transformed through the pulse transformer T_1 to fire the SCR (Q_4) permitting the current to flow through inductor L_A , SCR (Q_4), transformer T_2 primary for Trip Current Indicator, inductor L_B , Zener Z_4 , contact 52a and Trip Coil 52T. The time delay of this circuit is approximately 1ms. Capacitor C_3 is initially charged by the Trip Battery voltage through inductor L_A , resistor R_9 , and Zener Z_3 when the breaker or switch is closed bypassing T_2 to avoid a false indication. When Q_4 fires, C_3 discharges through SCR (Q_4), Zener Z_2 ,

and resistor R_8 . This discharge provides the holding current for Q_4 for about 1ms that is long enough for the current through inductive

Trip Coil to reach the required holding current for Q_4 . T_1 has two secondary windings, the second of which is connected similar to a Q_4 circuitry for double-tripping function.

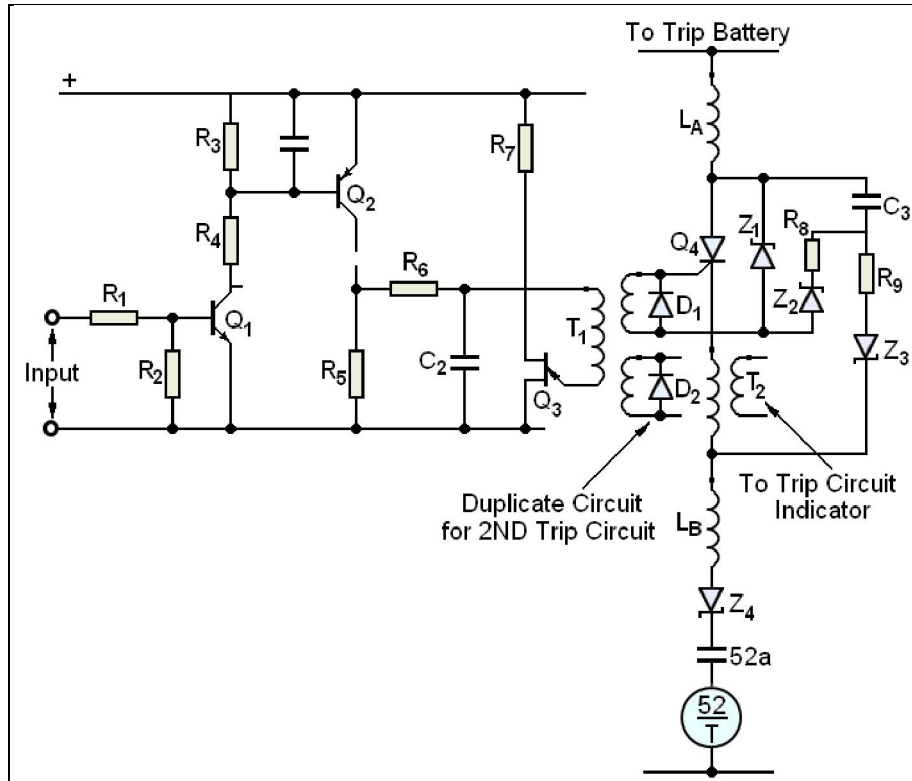


Fig. 3.3-4 Circuit Breaker Trip Coil Initiation Circuit

The transformer T_2 drives the Trip Current Indicator warning device when the Circuit Breaker is tripped. Except for the transformer T_2 , the circuitry associated with Q_4 provides reliability. The diodes $D1-2$ serve as gate protection by clipping the undesired negative pulses, if any, at the gate allowing only positive pulses to trigger the SCR gate. The Zener Z_1 is rated such that it provides over-voltage protection to the SCR Anode to Cathode when switched off by clipping high voltage transients on the battery leads, preventing false triggering. The two winding reactors L_A and L_B suppress any transients that could be transmitted through the inter-winding capacitance of T_1 or between the trip circuit and other logic circuit wiring. Zener Z_4 prevents shock excitation from setting up high frequency oscillation, which might reverse the current through Q_4 and returning to a blocking state.

CIRCUIT BREAKER TRIP INDICATOR AND ALARM CIRCUIT

A typical Circuit Breaker trip indicator and alarm logic is shown in Fig. 3.3-5 with SCR (Q_4) and transformer (T_2) in the Trip circuit. The transformer core uses a square hysteresis loop material to produce a very small exciting current and negligible inductive reactance when saturated. When trip current flows (after Q_4 fires), the circuit of R_1 , C_1 , R_2 and R_3 stretches a 2ms pulse at the secondary of T_2 into 6ms at the output of Q_2 , using 20VDC supply.

The input signal turns on both Q_1 and Q_2 to charge capacitor C_2 . When the voltage builds up to the trigger voltage (V_p) of the uni-junction transistor, Q_3 fires to trigger the gate of SCR (Q_4), energizing the indicating light (L) at the Anode terminal. The conduction of Q_4 triggers gate of SCR Q_5 through R_{10} from the bias voltage developed across R_{11} , energizing Alarm Relay (T). Even if the indicating light (L) circuit is open, the UJT (Q_3) output can still gate SCR Q_5 . The indicating lights are the solid-state equivalent of mechanical indicating targets. Red lenses are used to indicate tripping or to indicate which sensing unit signaled a trip. Amber lenses indicate general alarms. Blue lenses indicate testing. Sixty-V lamps operated at 48V or 120V lamps operated at 96V provide filament life of more than 30,000 hours.

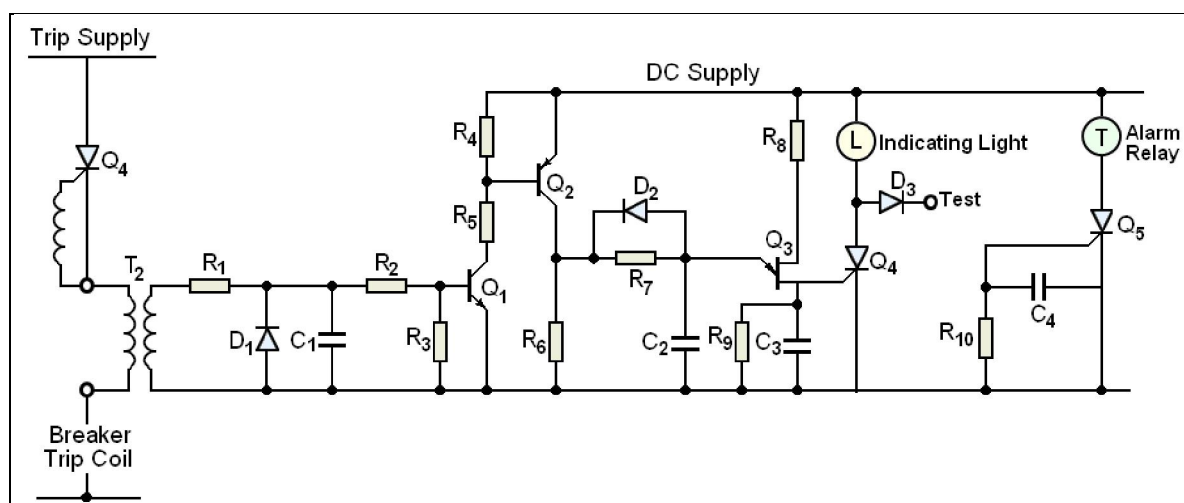


Fig. 3.3-5 Breaker Trip Indicator and Alarm Circuit

TIME OVERCURRENT RELAY

Static O/C Relays offer several advantages such as Reduced VA consumption (7mVA -100mVA) as compared to electromechanical Relays. Therefore, the performance of the CT under short circuit condition is improved with reduced size of CT. The Static Relays have more accurate time-current characteristics.

Static O/C Relays are not affected by vibrations unlike electromechanical Relays.

An electronic relay has, generally, the following functional blocks:

- Input circuit comprising: main CT, auxiliary CT, current setting switch, RC filter.
- Rectifier with smoothing circuit.
- Level detector
- Amplifier
- Tripping Relay

In O/C time delay Relays a time delay circuit is added between the rectifier and level detector to achieve desired time characteristics.

The O/C Relays without directional feature can be considered a single actuating quantity Relays. The directional O/C Relays are considered a double actuating quantity Relays, the direction of power flow is sensed by the phase angle between current and voltage.

Single Actuating Quantity Relays:

Fig. 3.3-6 shows a simplified block diagram for the single actuating O/C Relay (non-directional).

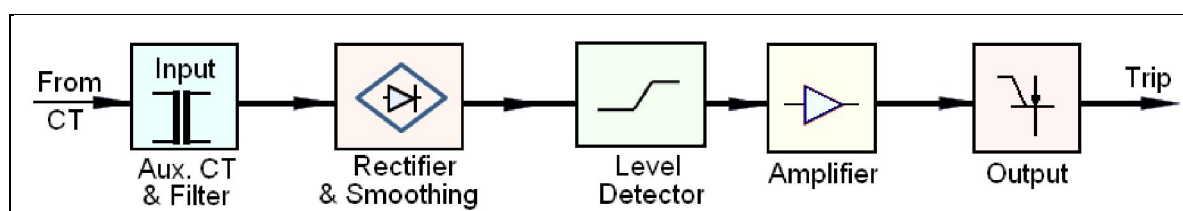


Fig. 3.3-6 Simplified Block Diagram OF A Single Actuating Quantity Relay

The secondaries of CTs are connected to a summing circuit and the output of this summing circuit is given to intermediate CT. The output of CT is Supplied to full wave rectifier bridge. The rectified output is given to measuring element (level detector), and the measuring element determines whether the quantity has reached the set value or not.

After operation of the measuring element (level detector) the output is amplified and then given to the output device, which is connected to the circuit breaker trip circuit. If a time delay is desired, a timing circuit is introduced before the level detector.

BASIC PRINCIPLE OF STATIC O/C RELAYS

Fig. 3.3-7 shows a simplified functional blocks diagram for a static O/C Relay.

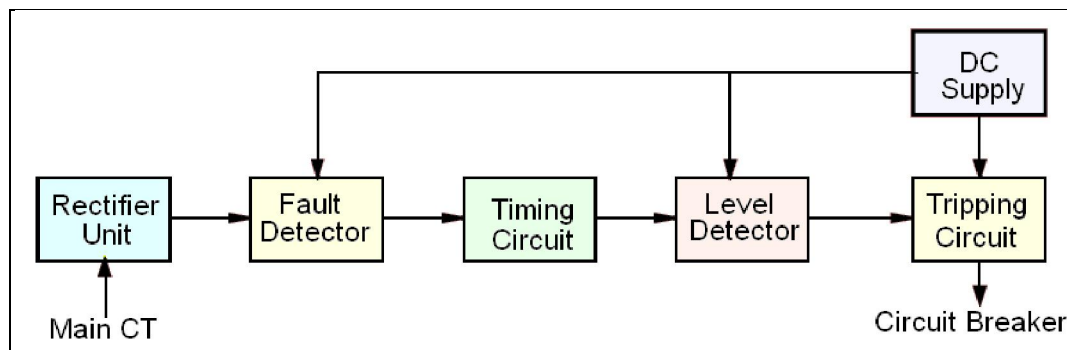


Fig. 3.3-7 Simplified Block Diagram of Basic Static O/C Relays

The incoming signal from the CT is rectified, and passed into the fault detector and from here into the timing circuit. When this times out, the trip detector will trigger the tripping circuit. Note that the Relay must be provided with DC power to operate the tripping circuit, the trip level detector and the fault detector. Fig. 3.3-8 shows schematic of Basic Static O/C Relays and Fig. 3.3-9 shows Block Diagram of Basic Static O/C Relays.

In Fig. 3.3-8, the secondary current of line CT is generally not suitable for static Relay operations (it is high), so the intermediate CT reduces the current further to 1 amp. So that it is suitable for static Relay circuits.

The input functional block comprises the following:

- Auxiliary CT
- Current selector
- Filter for suppressing harmonics
- Spike suppressor for protecting static Relays from over voltage spikes which are harmful for the Relay components.

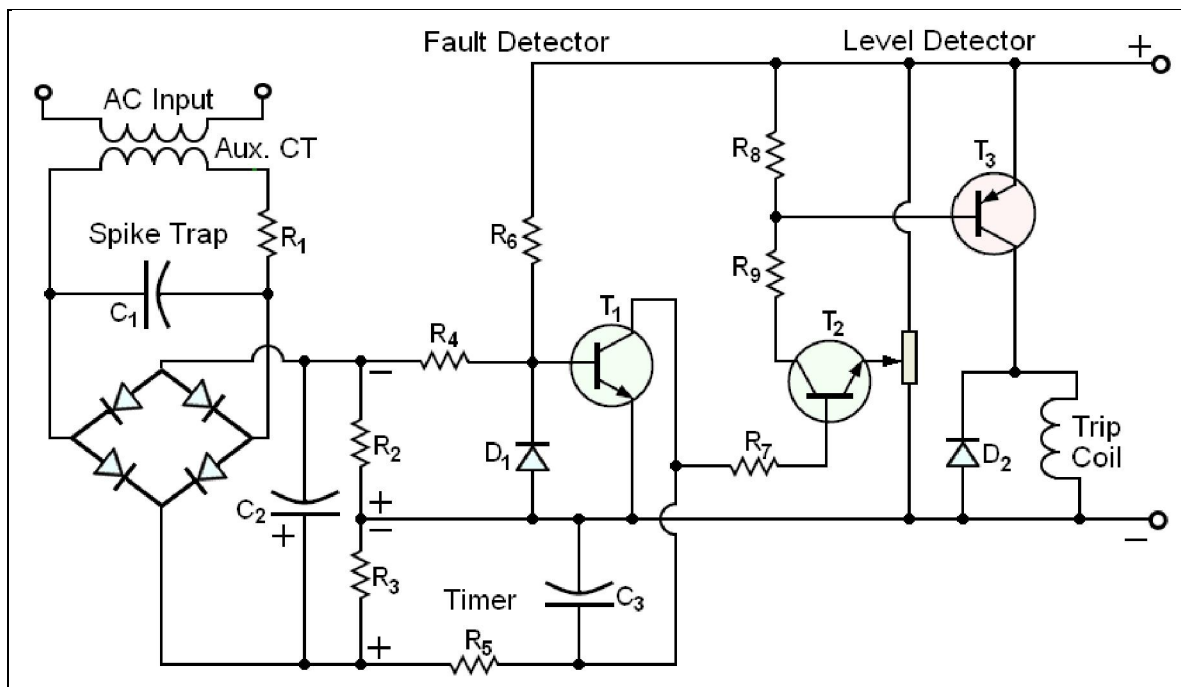


Fig. 3.3-8 schematic of Basic Static O/C Relays

The desired current range can be selected by setting the tap at the desired position. The ac derived from auxiliary CT may contain harmonics particularly under short circuit conditions. Hence filters are used and spike suppressors also are used to protect the semiconductor devices.

The current rectified is rectified and smoothed to eliminate ripple in the output waveform. In the instantaneous Relay the output of rectifier is given to a level detector and then to amplifier. In time O/C Relays the rectifier output is supplied to level detector (I) and a timing circuit is added in between the level detector (I) and level detector (II) see Fig. 3.3-9.

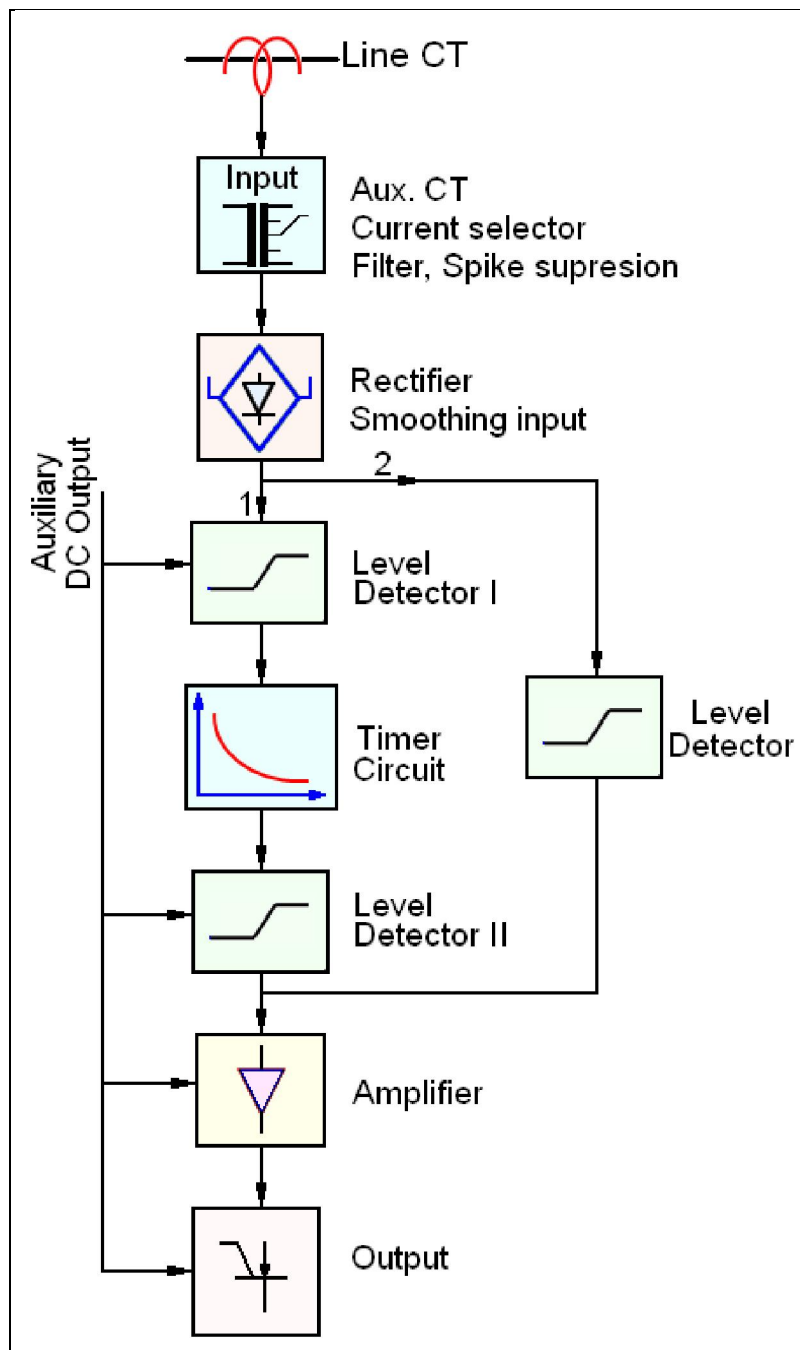


Fig. 3.3-9 Simplified Block Diagram of A Static Over-Current Relay
(1) With Time Delay , (2) Without Time Delay

The output of level detector is amplified and the output of the amplifier is given to the output stage of the static Relay. The output stage of the static Relay may be either moving coil permanent magnet DC relay or thyristor in series with the trip coil.

- Instantaneous over-current relay.
- Inverse Time Over-Current Relay.

Fig. 3.3-10 shows an example of static instantaneous O/C Relay in block diagram and detailed circuit. In this circuit the input AC. current is converted into proportional voltage using transactor and then rectified. The magnitude of this rectified voltage is then compared against a preset pick-up value, and if it exceeds it, a signal is given to the output transistor through an amplifier then the output Relay.

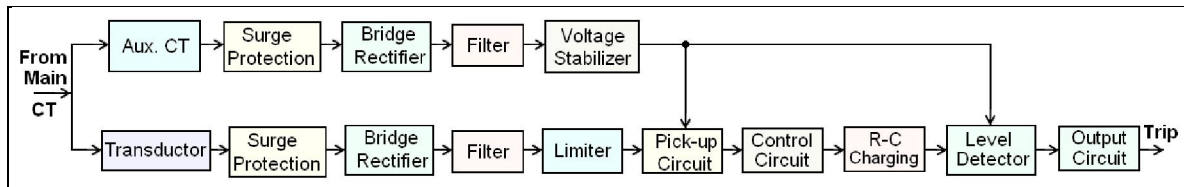


Fig. 3.3-10 Block diagram for IDMT O/C Relay

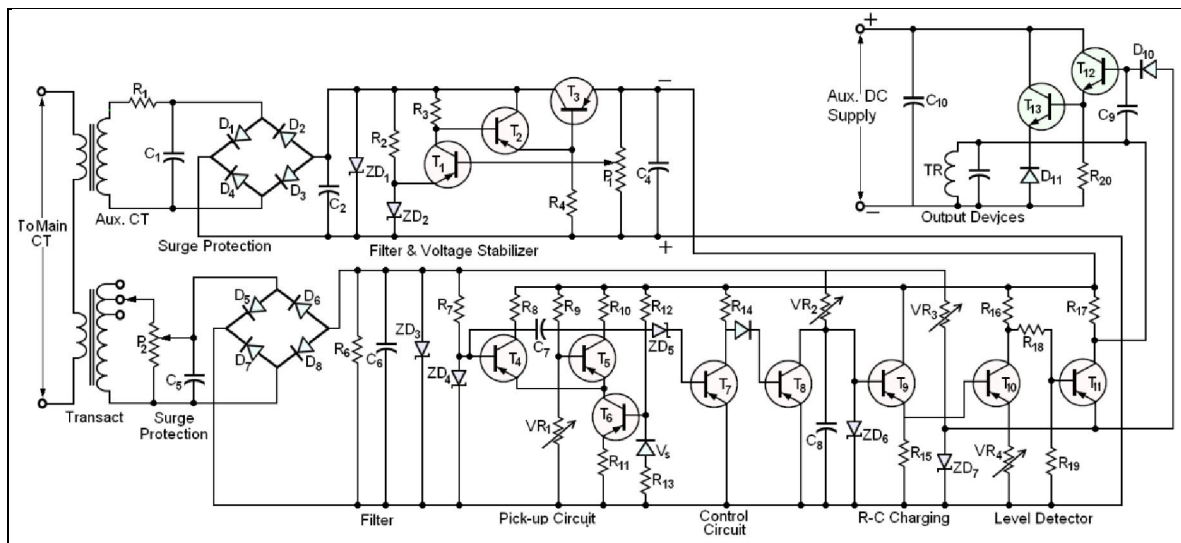


Fig. 3.3-11 Example of IDMT Over-Current Relay

Fig. 3.3-11 shows an example of IDMT OVER-CURRENT Relay with built in stabilized power supply. In this circuit the current signal is converted to a proportional voltage signal. The voltage then rectified and filtered and its level is checked by a limiter circuit. A pick up circuit compares this voltage with a preset value and gives a signal to control circuit if it exceeds this value. It is applied to a charging circuit and a level detector whose output controls the trip Relay and the operation indicator.

Fig. 3.3-12 shows the block diagram of inverse time O/C Relay (ASEA). As mentioned above, the input current is converted to a voltage by the input transformer

and then rectified, smoothed, and compared with a reference voltage. At pick up value the starting Relay picks up. Charging of a Relay with definite time curve is done with a stabilized voltage.

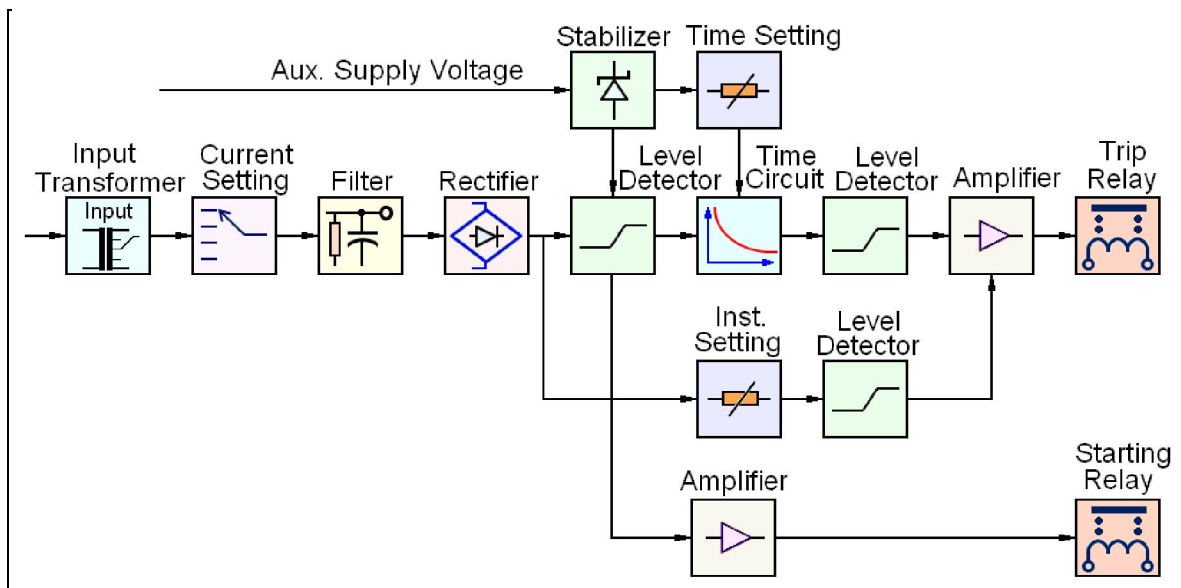


Fig. 3.3-12 Block Diagram OF Inverse Time O/C Relay (ASEA)

For a Relay with inverse time curve, charging takes place from a voltage proportional to current. The required time curve is obtained through a combination of zener diodes and RC circuit. The trip Relay then picks up. The starting Relay mentioned above is used for instantaneous tripping, or blocking of other Relays where necessary, or operation of counter recording numbered faults.

MCGG OVER-CURRENT RELAYS

- The Over-Current Relays type MCGG are available in 1 ϕ , 2 ϕ and 3 ϕ plug-in module types.
- These relays are designed so that different versions are used with separate measuring boards for each phase or earth fault input.
- Alternatively, phase inputs may be combined on to one board for poly-phase measurement, as per the catalog.

- These boards with other circuits are contained in a single plug-in module that is supplied in Midos case sizes 4, 6, and 8 incorporating one or two terminal blocks for external connections, depending on the application.
- The removal of the module automatically short-circuits the current transformer connections by means of safety contacts within the case.
- For added security, when the module is removed from the case, the CT circuits are short-circuited before the connections to the output contacts and DC supply are broken.

Fig. 3.3-13 shows the MCGG 22 module.

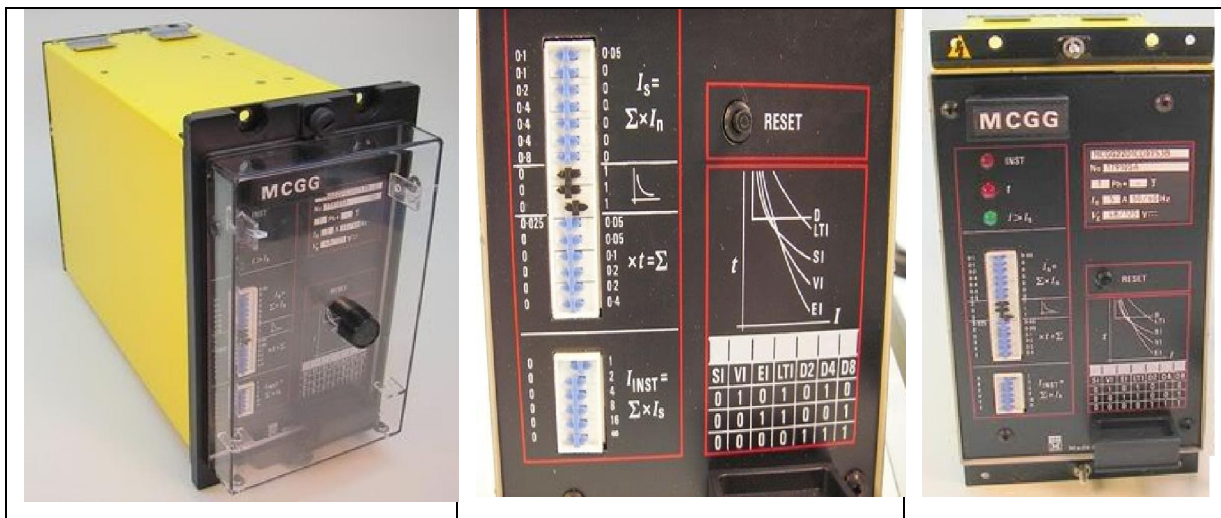


Fig. 3.3-13 MCGG Static Overcurrent Relay

Each measuring board has a built-in “power off” memory feature for the time delayed and instantaneous LED indicators.

Power to each measuring board may be tested while the relay is in service without affecting the current measurement.

A test mode is also available to carry out a Trip Test on the output relays during which the current measurement is inhibited.

When required, directional control may be exercised over the relay by connecting an output contact from directional relay type METI to the terminals provided.

Separate output contacts, capable of CB tripping, are provided for time-delayed phase faults, time-delayed earth faults, and instantaneous earth fault operations.

These relays have the provision to make the instantaneous inoperative and has separate Trip Test feature.

MCGG OVER-CURRENT RELAY APPLICATIONS

These relays are used for protection against over-current and short-circuit conditions in the system.

The relays can be used in applications where time-graded over-current and earth fault protection is required.

The relays can also be used to provide selective protection for overhead and underground distribution feeders.

Other applications include backup protection of power transformers, generators, HV feeder circuits, transmission lines, and the protection of neutral earthing resistors.

The MCGG relays are also used in combination with type directional relays for directional control.

MCGG RELAY OPERATING CHARACTERISTICS

The relay has four inverse time curves and three definite time ranges, as shown in Table 2.

SWITCH POSITIONS		OPERATING CHARACTERISTICS	
0	1		
	• • •	Trip Test	
• • •		Standard Inverse	$t = \frac{0.14}{(I^{0.02} - 1)} \text{ sec(SI)}$
• •	•	Very Inverse	$t = \frac{13.5}{(I - 1)} \text{ sec(VI)}$
• •	•	Extremely Inverse	$t = \frac{80}{(I^2 - 1)} \text{ sec(EI)}$
•	• •	Long Time Earth Fault	$t = \frac{120}{(I - 1)} \text{ sec(LT)}$
• •	•	Definite Time 2 seconds	D2
•	• •	Definite Time 4 seconds	D4
•	• •	Definite Time 8 seconds	D8

Table 3.3-1 MCGG Relay Operating Characteristics with Switch Positions

EXAMPLE 3.3-1

The Standard Inverse Operating time of a 5A MCGG OC Relay is:

$$t = \frac{0.14}{I^{0.02} - 1} \text{ sec (SI)}$$

SOLUTION

$$t = \frac{0.14}{I^{0.02} - 1} = \frac{0.14}{5^{0.02} - 1} = \frac{0.14}{0.03271} = \mathbf{4.28\text{sec (SI)}}$$

EXAMPLE 3.3-2

The Very Inverse Operating time of a 5A MCGG OC Relay is:

$$t = \frac{13.5}{I - 1} \text{ sec (VI)}$$

SOLUTION

$$t = \frac{13.5}{I - 1} = \frac{13.5}{5 - 1} = \frac{13.5}{4} = \mathbf{3.38\text{sec (VI)}}$$

EXAMPLE 3.3-3

The Extremely Inverse Operating time of a 5A MCGG OC Relay is:

$$t = \frac{80}{I^2 - 1} \text{ sec (EI)}$$

SOLUTION

$$t = \frac{80}{I^2 - 1} = \frac{80}{5^2 - 1} = \frac{80}{24} = \mathbf{3.33\text{sec (EI)}}$$

EXAMPLE 3.3-4

The Long Time Earth Fault Operating time of a 5A MCGG OC Relay is:

$$t = \frac{120}{I - 1} \text{ sec (LT)}$$

SOLUTION

$$t = \frac{120}{I-1} = \frac{120}{5-1} = \frac{120}{4} = 30\text{sec (LT)}$$

MCGG RELAY SETTINGS

Separate setting switches for each measuring board are provided on the front panel. The setting switches on the front panel are used to select time/current characteristic, current, and time multiplier settings.

The current/time characteristic selection is carried out by means of three switches, identified as symbol on the front panel, as shown in Table 3.3-2.

The time given by each of the operating characteristics must be multiplied by the time-multiplier to give the actual operating time of the relay.

This control is marked $Xt = \Sigma$, where Σ is the sum of all the switch positions.

The range of the multiplication is from $0.05\times$ to $1.0\times$ in steps of 0.025 .

The multiplier acts as a conventional time multiplier on the current dependent characteristics and gives the following time ranges, as shown in Table-3, for the definite time characteristics.

OPERATING CHARACTERISTICS	TIME RANGE
2	0.1 to 2.0 in 0.05s steps
4	0.2 to 4.0 in 0.1s steps
8	0.4 to 8.0 in 0.2s steps

Table 3.3-2 Operating Characteristics and Time-multiplier Ranges

CURRENT SETTINGS (TIME-DELAYED ELEMENT)

The current setting control is marked as $I_s = \Sigma \times I_n$, where Σ is the sum of all the switch positions, I_s acts the current setting in Amps, and I_n is the relay rated current in Amps.

Each measuring board provides a setting range from $0.05 \times I_n$ to $2.4 \times I_n$, in steps of $0.05 \times I_n$.

CURRENT SETTINGS (INSTANTANEOUS ELEMENT)

Control setting of the instantaneous element is marked as $I_{inst} = \Sigma \times I_s$, where Σ is the sum of all switch positions, and I_s is the time-delayed element setting in Amps. When all switches are set to the left (0 setting) or when the lowest switch is set to infinity regardless of the positions of the other switches, the feature is inhibited. The adjustment range of finite settings is from $1 \times$ to $31 \times$ in unity steps.

TRIP TEST

Current measurement is inhibited by setting the curve selection switches to 111. This causes all three LEDs to flash once per second. If the RESET pushbutton is then pressed for approximately 6 seconds, both output relays associated with that measuring board will operate.

POWER SUPPLY HEALTHY TEST

If the reset pushbutton is pressed while the relay is in service, all LEDs illuminate, indicating that there is power to the measurement boards. The LEDs are reset on releasing the pushbutton. During this test, normal current measurement is allowed.

HANDLING PRECAUTIONS

1. Use a conductive wrist strap while removing a module or touching the electronic components, printed circuit track or connectors.
2. Do not exceed the thermal rating of the relay under test.
3. Do not use lamp or bell to monitor reed relay contact operation as this may cause damage due to excessive current.
4. Check that CT shorting switches are closed across the case terminals when the module is withdrawn.

5. Make sure that the trip is isolated for the individual phase relay under test only and not for all three phases.

INSPECTION, CLEANING AND MAINTENANCE

Perform visual inspection, cleaning and maintenance in accordance to:

RMS-5000-01-I: “Initial Inspection and Cleaning of Metering, Relaying and Communication Equipment”.

ROUTINE MAINTENANCE TESTS

Perform the following routine maintenance tests with ESPD settings and record the test results in Data Record sheet, RMS-5285-01-M.

MINIMUM PICKUP TEST

Using Fig. 3.3-14 and Table 3.3-3 for the test connections, apply just less than tap value current and increase slowly until the green LED (start) I>Is lights up.

The pick-up value should be $\pm 10\%$.

Record the value in the Data Record Sheet.

TIME CURVE TEST

Using Fig. 3.3-14 for the test connections, apply current 2, 3 and $5 \times$ tap value.

Compare the test results with the time curve or calculated value.

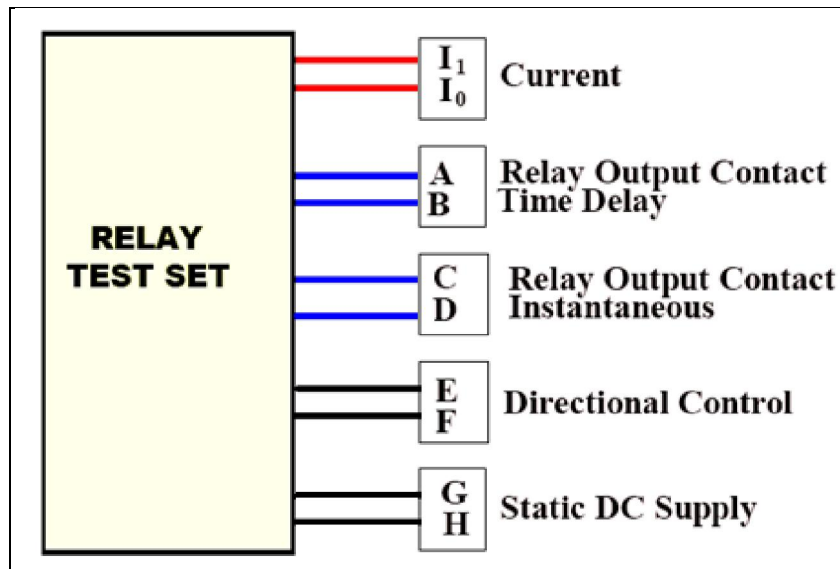


Fig. 3.3-14 Test set Connections for MCGG Over-Current Relay

Test the relay at given ESPD test point and check that RED LED (Time Delay Trip) lights up within $\pm 5\%$ ESPD setting.

Record the test results in the Data Record Sheet.

INSTANTANEOUS OVER-CURRENT TEST

Using Fig. 3.3-14 and Table-2 for the test connections, apply close to instantaneous set value current. The instantaneous unit operates and RED LED (Instantaneous Trip) lights up within $\pm 10\%$ of the ESPD current setting. Then, record the test results in the Data Record Sheet.

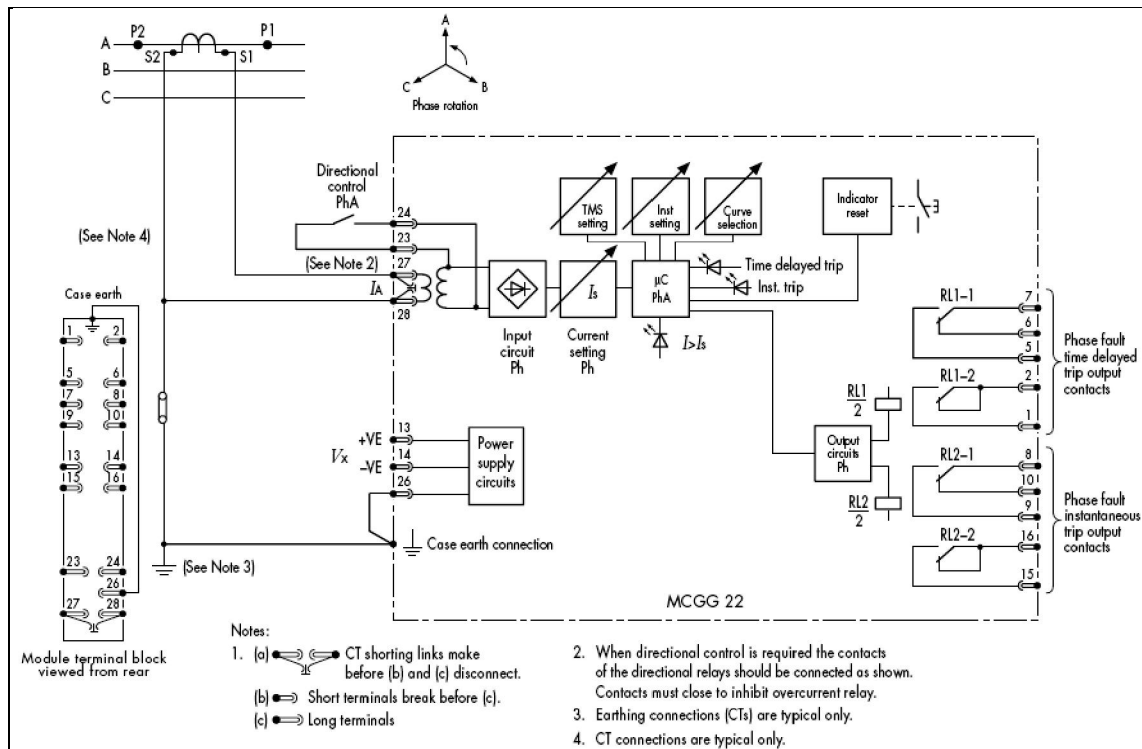


Fig. 3.3-15 MCGG 22 Over-Current Relay (1φ with Instantaneous Element)

MCGG 22 RELAY TROUBLESHOOTING CONCEPTS

As shown in Fig. 3.3-15 output relays R_{L1} or R_{L2} energize under time-delayed or instantaneous tripping on phase faults, respectively. If the relay does not operate at all, the first thing to check is the DC power supply (V_x) at terminals 13(+) and 14(-) under normal operating conditions.

If there is no DC voltage measured, the power supply circuits must be defective. If either of the output relays $RL1$ or $RL2$ does not energize under fault, the relative contacts $RL1-1/RL1-2$ or $RL2-1/ RL2-2$, respectively, would not change-over and hence no tripping will occur.

In that case, either respective relay or the output circuits (ph) driving the relay may be defective.

Looking at the input signal to the output circuits (ph), observe if $I > I_s$ LED is lit under faulty condition.

If I>Is LED and either of the two time-delayed or instantaneous trip LEDs on μ C (phA) circuit block is lit and the input signal to the output circuits (ph) is present, the output circuits (ph) driving the relays RL1 or RL2 may be defective.

If there is no output from μ C (phA) circuit block to the output circuits (ph), and either of the two the respective Trip LEDs is lit, the output circuit in μ C (phA) block may be defective.

If LED indicators cannot be reset after the fault is cleared, either the RESET push button is defective or the related Indicator Reset circuit may be defective.

If the trip LEDs light up on fault and the relay output contacts operate normal, but I>Is LED is never lit, I>Is LED must be defective.

If the relay operates above or below the time-delayed or instantaneous current settings as the case may be, the respective comparator circuitry inside the μ C (phA) circuit block may be assumed to be defective.

If the Current Setting (ph) in Is block is changed up or down and there is no output level change at its output terminal when over-current is applied to the input and no tripping occurs under fault, the current limiting circuitry in Is block may be defective.

If there is no input to the Current Setting block (Is) from the Rectifier block, the rectifier circuit may be defective.

SUMMARY

- The secondary current of line CT is generally not suitable for static Relay operations (it is high), so the intermediate CT reduces the current further to 1 amp. so that it is suitable for static Relay circuits.
- Static O/C Relays offer several advantages such as Reduced VA consumption (7mVA -100mVA) as compared to electromechanical Relays.
- The Static Relays have more accurate time-current characteristics.
- Static O/C Relays are not affected by vibrations unlike electromechanical Relays.
- Static Relays must be provided with DC power to operate the tripping circuit,

- The current measurement in MCGG Over-Current Relays is inhibited during the test mode to carry out a Trip Test on the output relays.
- The MCGG Over-Current Relays are used for:
- The setting switches on the front panel of MCGG Over-Current Relays are used to select time/current characteristic, current, and time multiplier settings.
- The time given by each of the operating characteristics of MCGG Over-Current Relays must be multiplied by the time-multiplier to give the actual operating time of the relay.
- The range of the multiplier is from $0.05\times$ to $1.0\times$ in steps of 0.025 for current/time characteristics of MCGG Over-Current Relays.
- Each measuring board of MCGG Over-Current Relay provides a setting range from $0.05\times I_n$ to $2.4\times I_n$, in steps of $0.05\times I_n$.
- During power supply healthy test of MCGG Over-Current Relay, if the RESET pushbutton is pressed while the relay is in service, all the LEDs are illuminated, indicating that there is power to the measurement boards allowing normal current measurement and the LEDs will be reset on releasing the pushbutton.
- Make sure that the trip is isolated for the individual phase relay under test only and not for all three phases.
- During Time Curve Test on an MCGG Over-Current Relay, when applying current 2, 3 and $5 \times$ tap value, the RED LED (Time Delay Trip) should light up within $\pm 5\%$ of given Time Curve.

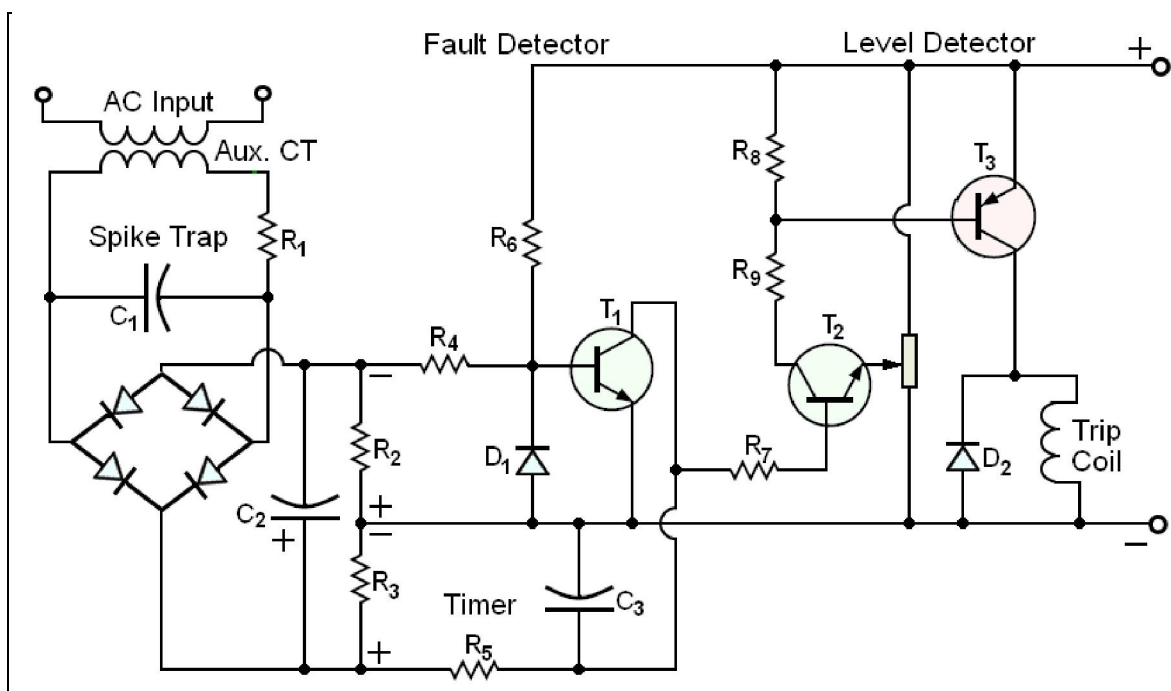
REVIEW EXERCISE

STATIC O/C RELAYS

- Static Relays have _____ accurate time-current characteristics compared to electromechanical Relays.
 - More
 - Less
- Electromechanical O/C Relays are not affected by vibrations unlike Static Relays.
 - True
 - False
- Draw Simplified Block Diagram of Basic Static O/C Relay.

Basic principle of static O/C Relays:

- Study the Figure Shown below then answer the following questions.



-

-

- a) 1ϕ
c) 3ϕ
- b) 2ϕ
d) All of above

- a) True b) False

- a) True b) False

- a) b) c)

10. The Long Time Earth Fault Operating time of a 5A MCGG OC Relay is ____

$$\text{seconds.} \quad \mathbf{t = \frac{120}{I - 1} \text{ sec (LT)}}$$

- a) 15 b) 30
c) 3 d) 10

11. The control marked $X_t = \Sigma$ on front panel of the MCGG OC Relay indicates the _____ of all the switch positions.

- a) product b) sum
c) difference d) none of above

12. The current setting control of time-delayed element of MCGG Over-Current Relay is marked as $I_s = \Sigma \times I_n$.

- a) True b) False

13. Current measurement in MCGG Over-Current Relay is inhibited during Trip Test by setting the curve selection switches to ____ causing all three LEDs to flash once per second.

- [illegible]

14. Use a conductive _____ while removing a module or touching the electronic components, printed circuit track or connectors on MCGG Over-Current Relays.

15. Check that CT shorting switches are open across the case terminals of relay when the module is withdrawn.

- a) True b) False

TASK 3.3-1

TESTING STATIC OVERCURRENT RELAY

OBJECTIVES

Upon completion of this task, the trainee will be able to:

1. Apply Over-Current Setting.
2. Perform Minimum Pickup Test.
3. Perform Time-Curve test.
4. Perform Instantaneous Over-Current Test.
5. Perform Directional Control Test.
6. Perform Calibration.
7. Fill out data record sheet.

TOOLS, MATERIALS & REQUIREMENTS

MCGG 22 Over-Current Relay or any other static overcurrent relay.

- 1 - Over-Current test set (with timing facilities or separate timer).
- 1 - DC power supply (suitable for relay auxiliary voltage).
- 1 – Multi-meters (DVMs).

HANDLING PRECAUTIONS

A person's normal movements can easily generate electrostatic potentials of several thousand volts. Discharge of these voltages into semiconductor devices when handling electronic circuits can cause serious damage, which often may not be immediately apparent but the reliability of the circuit will have been reduced.

The electronic circuits in products are completely safe from electrostatic discharge when housed in the case. Do not expose them to the risk of damage by withdrawing

modules unnecessarily.

Each module incorporates the highest practicable protection for its semiconductor devices. However, if it becomes necessary to withdraw a module, the following precautions should be taken to preserve the high reliability and long life for which the equipment has been designed and manufactured:

- Before removing a module, ensure that you are at the same electrostatic potential as the equipment by touching the case.
- Handle the module by its front-plate, frame, or edges of the printed circuit board. Avoid touching the electronic components, printed circuit track or connectors.
- Do not pass the module to any person without first ensuring that you are both at the same electrostatic potential. Shaking hands achieves equal potential on both bodies.
- Place the module on an antistatic surface, or on a conducting surface, which is at the same potential as you.
- Store or transport the module in a conductive bag.
- More information on safe working procedures for all electronic equipment can be found in BS5783 and IEC 147-0F documents.
- When you are making measurements on the internal electronic circuitry of the relay, it is strongly advisable that you are earthed to the case with a conductive wrist strap. Wrist straps should have a resistance to ground between 500k-10M ohms. If a wrist strap is not available, you should maintain regular contact with the case to prevent the buildup of static. Instrumentation, which may be used for making measurements, should be earthed to the case whenever possible.

PROCEDURE

MINIMUM PICKUP TEST

1. Using Fig. 1-1(a,b) and Table 1-1(b) for the test connections, connect the over-current test set to the relay.
2. Check the rated auxiliary voltage V_X on the front plate and connect a suitable

smoothed DC supply or station battery supply to relay terminals 13(+ve) and 14(-ve).

3. Apply just less than tap value current and increase it slowly to the value until the green LED (start) $I > I_s$ lights up.

The pickup value should be $\pm 10\%$.

4. Record the test results in the Data Record Sheet.

TIME CURVE TEST

5. Using Fig. 1-1(a,b) and Table 1-1(b) for the test connections, apply current 2, 3 and $5 \times$ tap value.
6. Compare the test results with the time curve or calculated values.
7. Test the relay at given ESPD test point and check that RED LED (Time Delay Trip) lights up.

The tolerance should be within $\pm 5\%$.

8. Record the test results in the Data Record Sheet.

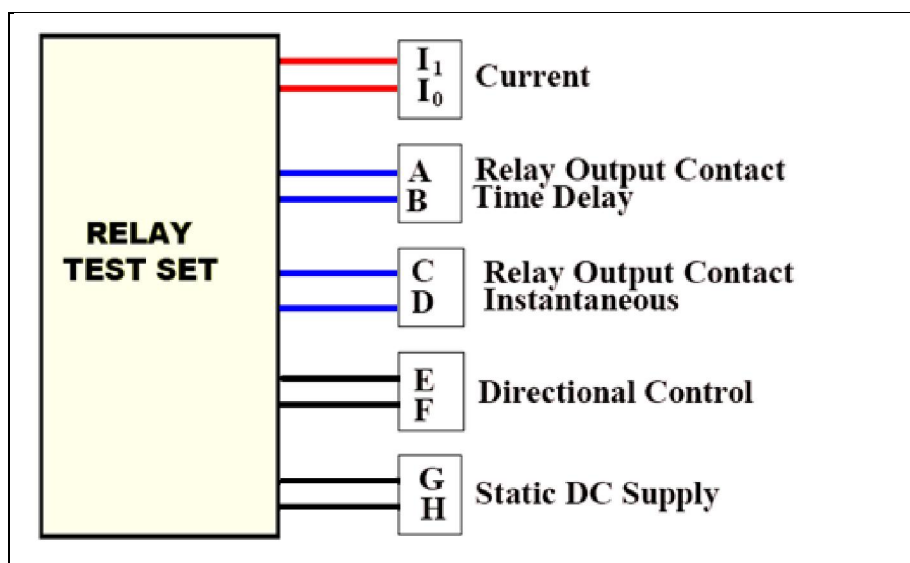


Fig. 1-1(a) Test Set Connections for MCGG 22 Over-Current Relay

TEST	I1	I0	A	B	C	D	E	F	G	H
Minimum Pickup	27	28	-	-	-	-	-	-	+13	-14
Timing Curve	27	28	5	7	-	-	-	-	+13	-14
Instantaneous	27	28	-	-	8	9	-	-	+13	-14
Directional Control	27	28	-	-	-	-	23	24	+13	-14

Table 1-1 Relay Stud Connections

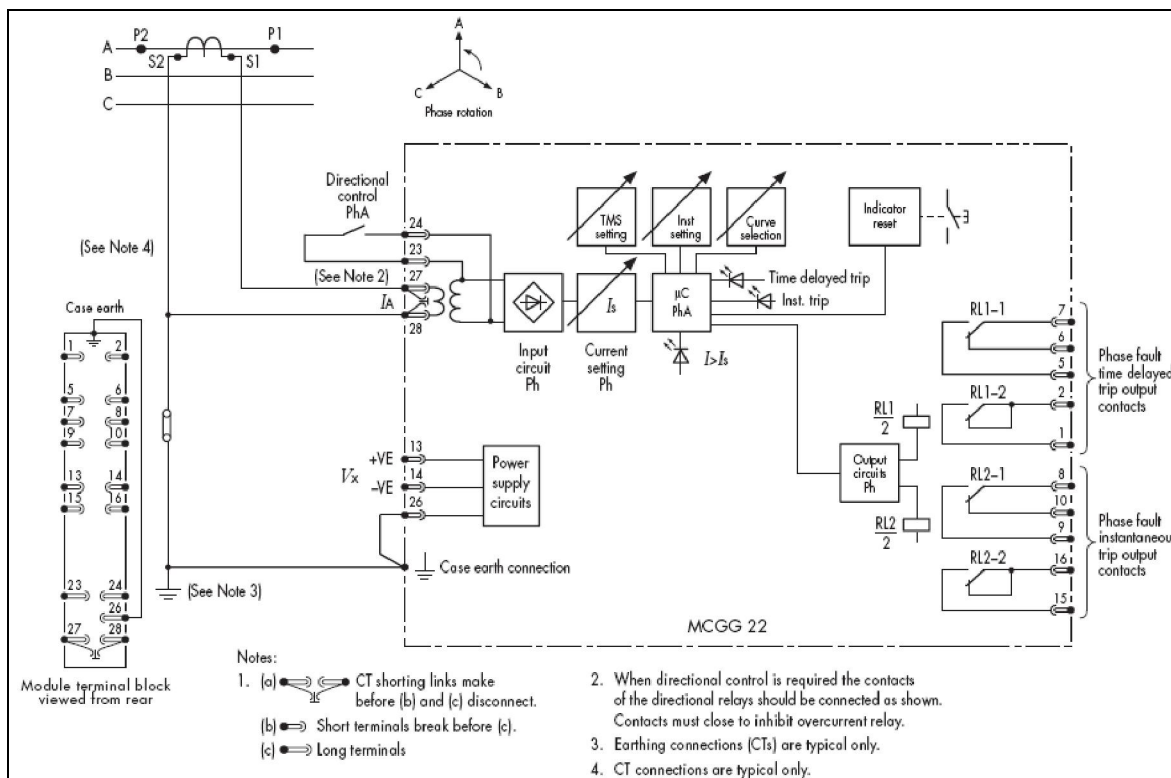


Fig. 1-1(b) MCGG 22 Over Current Relay

INSTANTANEOUS OVER-CURRENT TEST

- Using Fig. 1-1(a,b) and Table 1-1(b) for the test connections, apply close to instantaneous set value current, momentarily. The tolerance should be within $\pm 10\%$ of the set value.
- The instantaneous unit operates and red LED (Instantaneous Trip) lights up.
- Record the test results in the Data Record Sheet.

DIRECTIONAL CONTROL TEST

12. Simulate the operation of the directional relay by bridging the terminals 13, 14 to check blocking the operation of the MCGG relay.

RELAY TYPE MCGG FORM SHEET

SEC-ER POWER TRANSMISSION DEPARTMENT				Data Sheet 2 of 2	
MCGG Over-Current Relay				RMS-5305-01-M	
Station	Circuit			Bkr(s)	
Manuf.	Type			Style	
Range	CT Ratio			PT Ratio	
Device #(s)	Panel #			Phase(s)	
Relay #(s)					
ESPD SETTINGS					
	Time Characteristic Curve	Over-current Setting (Is)	Time Multiplier Setting	Instantaneous Setting (Iinst)	Test Point (It)
Phase Over- Current Relay		$\times I_n = \quad A$	$\times t =$	$\times I_s = \quad A$	
Ground Over- Current Relay		$\times I_n = \quad A$	$\times t =$	$\times I_s = \quad A$	
Directional Over-Current Relay		$\times I_n = \quad A$	$\times t =$	$\times I_s = \quad A$	
MINIMUM PICKUP TEST					
Test	Is	Pickup	Check box if GRN LED (I>Is)		
Phase A	A	A			
Phase B	A	A			
Phase C	A	A			
Ground	A	A			

PERFORMANCE SHEET

TIME CURVE TEST						
Test	Is	2 × Is (A)	3 × Is (A)	5 × Is (A)	Test Point	Check box if RED LED (Time Delay) lit
Phase A	A	s	s	s	s	
Phase B	A	s	s	s	s	
Phase C	A	s	s	s	s	
Ground	A	s	s	s	s	
SEC-ERB POWER TRANSMISSION DEPARTMENT					Data Sheet 2 of 2 RMS-5305-01-M Rev: 0 Date: 1998-04-15	
INSTANTANEOUS OVER-CURRENT TEST						
Test	Instantaneous Setting	Pick Up		Check Box if RED LED (Inst. trip) lit		
Phase A	A	A				
Phase B	A	A				
Phase C	A	A				
Ground	A	A				
DIRECTIONAL CONTROL TEST						
Test	Directional Relay Output Contact	Over-current Relay Operation Inhibited	Directional Relay Output Contact Open	Over-current Relay Operation Operational		
Phase A						
Phase B						
Phase C						
Ground						

TEST SET: _____

REMARKS: _____

TESTED BY: _____ DATE: _____

REVIEWED BY: _____ DATE: _____

ESPD SETTING SHEET(S) DATED: _____

STATIC DISTANCE RELAY

INTRODUCTION

The distance relay operates essentially by comparing phasors of voltage and current. In solid-state relay, as the circuits are interconnected, the two inputs must be converted to the same units, either both voltage and both current. For a voltage comparator (Fig 3.3-16), the current is passed through a replica impedance Z , which is tuned to the same value as the line. The voltage drop across this impedance I_Z is then fed into the amplitude comparator to be compared with the polarizing voltage from the line. In other types of relays, equivalent current values are compared. In this case the VT voltage signal is applied across the replica impedance, so as to produce proportional current.

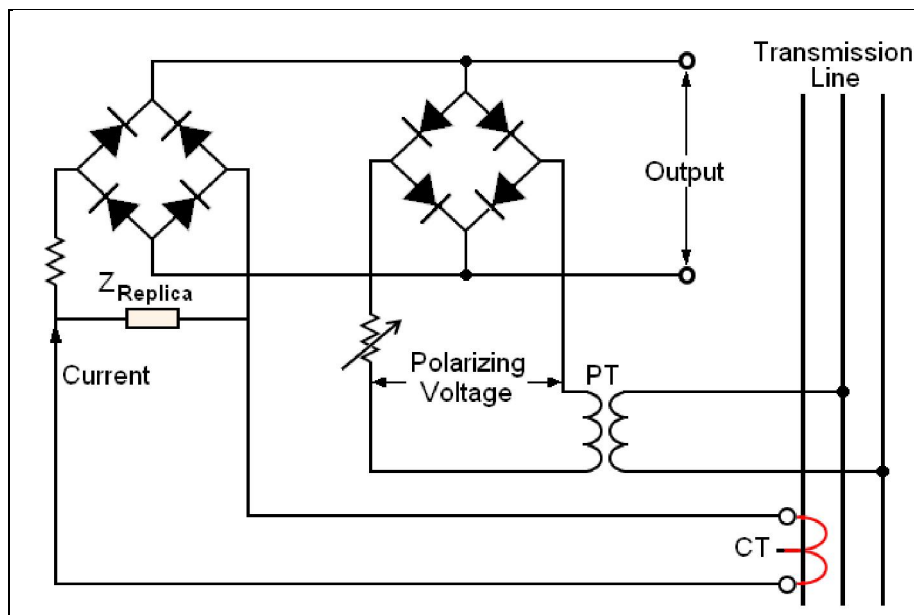


Fig 3.3-16 Simplified Distance Relay Voltage Comparator

SEQUENCE COMPARATOR

A precise method of controlling operation of the distance relay is by use of a sequence comparator. The characteristics of the static distance relay is shown in Fig 3.3-17. The

measured line voltage V , and the volt drop to the fault, I_Z , are plotted to their respective phase angles. The vectorial difference V minus I_Z can be used as an indication of fault location. V minus I_Z changes angle, as the fault location changes. This changing angle is compared with a fixed polarizing voltage in order to determine whether to restrain, or to operate the relay.

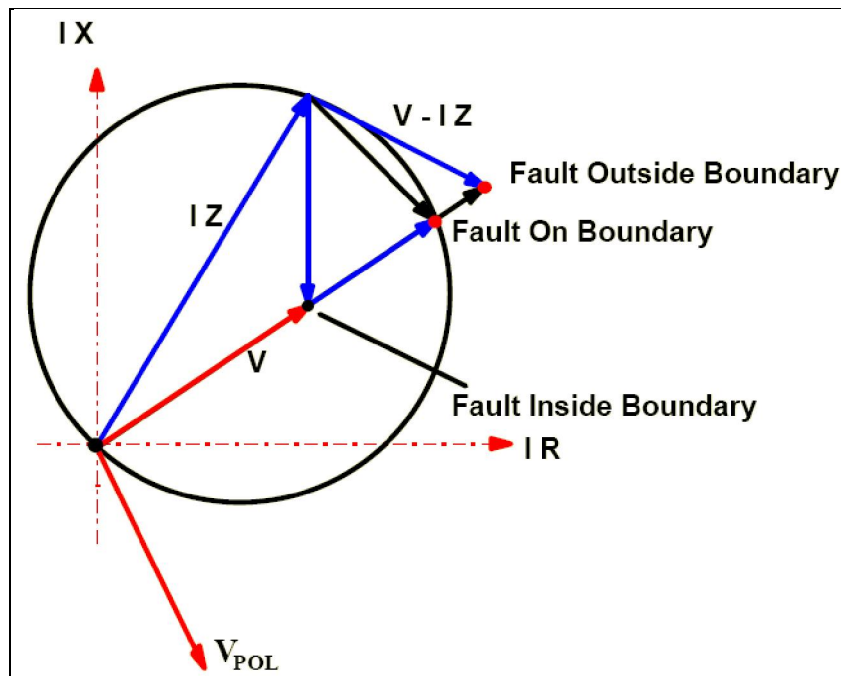


Fig 3.3-17 Characteristic Curve For Distance Relay

The polarizing voltage, V_p is arranged to lag the line voltage V by 90° . An internal fault is indicated when V minus I_Z lags the polarizing voltage. With an external fault V minus I_Z leads the polarizing voltage.

These two sinusoidal quantities (V_p and V minus I_Z), are fed into the sequence comparator, which converts them to a square wave and then compares the logic sequence (Fig 3.3-18). For simplicity let us call V minus I_Z , "A", and the polarizing voltage V_p "B".

The square wave has only two values high and low, represented by one and zero respectively.

For an external fault where "A" leads, the signal sequence will read, I_A, I_B ;

$0_A, 1_B, 0_A, 0_B, 1_A, 0_B, 1_A, 1_B, 0_A, 1_B$, etc.

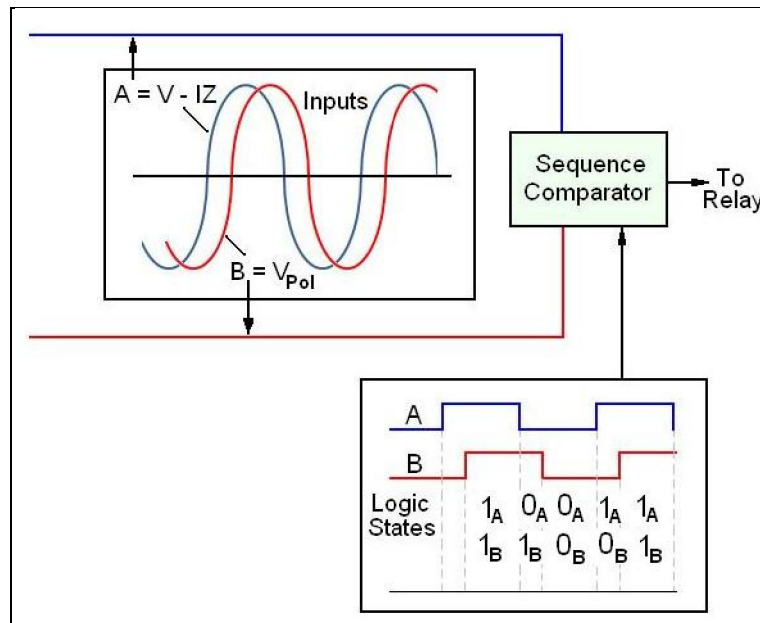


Fig 3.3-18 Sequence Comparator

The comparator's logic circuit examines the sequence of one's and zero's and determines whether the relay must restrain or operate. The 90° phase shift of the polarizing voltage is achieved digitally in the sequence comparator itself.

Fig. 3.3-19 shows a block diagram of one type of static distance relay. A two zone (zones 1 and 2) MHO relay is connected in each phase. An offset MHO relay is also connected in each phase. This acts as backup for zone 3 and as a starting switch for zones 1 and 2 relays. The two impedance units act to block tripping in the case of severe power swings.

Fig. 3.3-20 shows the connections for one of the MHO relays in the block diagram, Other relays and other phases are similarly connected. The auxiliary transformers permit adjustment of the impedance operating characteristics of the relay, which may be circular, offset, conic or other. The resistors and relay, which may be circular, offset, conic or other. The resistors and reactors in the CT secondaries permit duplication of the line impedance to produce the correct voltage drop and phase angle associated with the fault current. The resultant is then passed through the sequence comparator, which determines whether the relay should trip or restrain. The polarizing voltage for the comparator is supplied from the same phase, but this receives a 5 to 10X boost from the alternate phases, suitably corrected for phase angle of course.

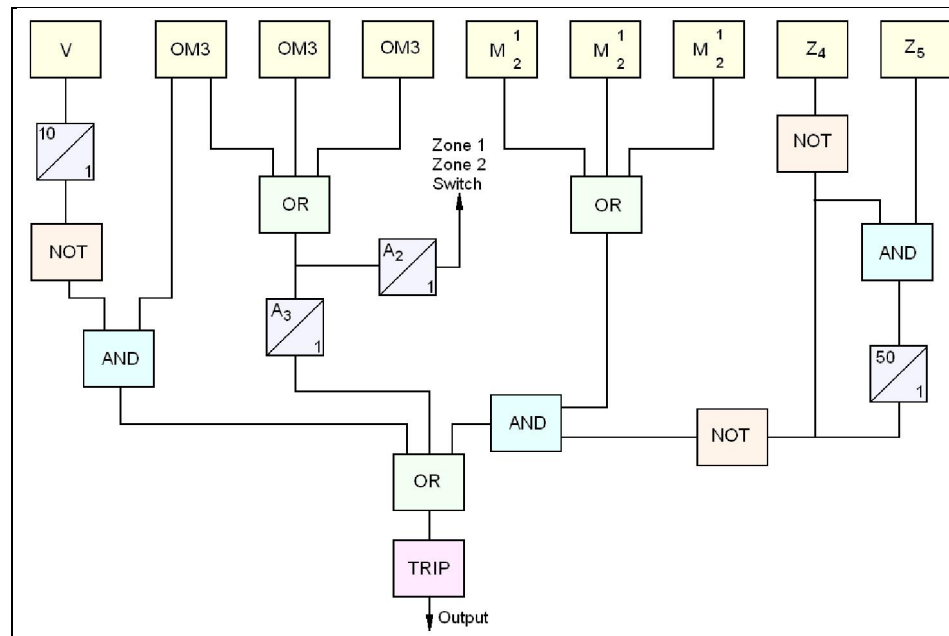


Fig 3.3-19 Static Distance Relay

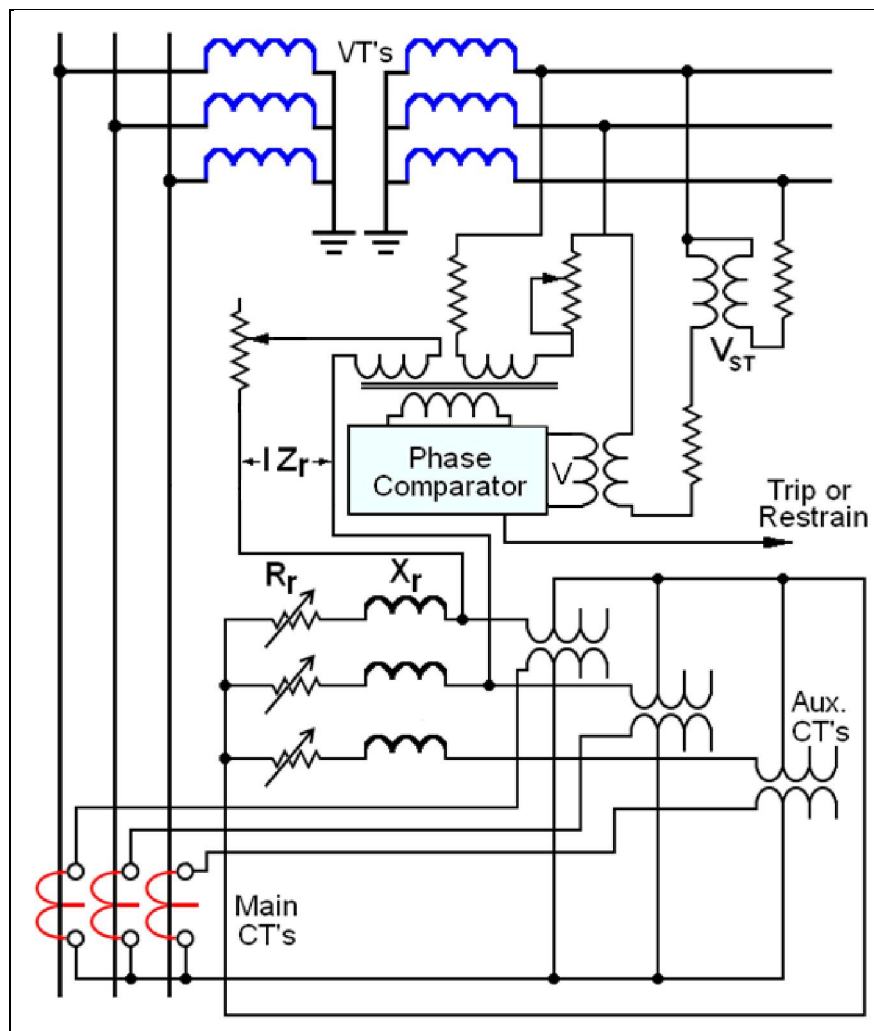


Fig 3.3-20 Mho Static Distance Relay

TYPES OF DISTANCE RELAYS

There are several types of distance relays:

CLASSICAL TYPE CHARACTERISTICS	<ul style="list-style-type: none"> a) Impedance b) Reactance c) MHO or Admittance (Angle Admittance) d) Ohm (Angle Impedance) e) Offset MHO f) Modified Impedance
NON CLASSICAL TYPE	<ul style="list-style-type: none"> g) Complex Characteristics Type h) Elliptical Characteristics Type i) Quadrilateral Characteristics Type

The characteristics on the complex impedance plane are shown in Fig 3.3-21.

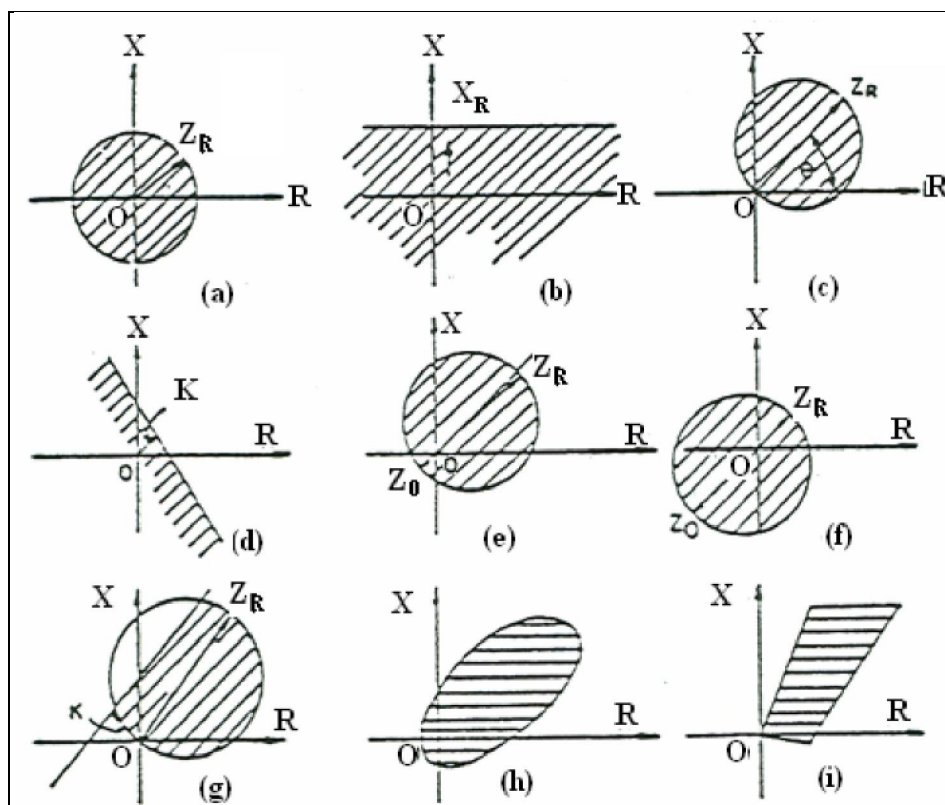


Fig 3.3-21 Distance Relay Characteristics

The derivation of these characteristics has already been discussed before. This discussion included characteristics (a) to (e) and (f) are the same except for the amount of offset and hence do not need separate discussion.

Characteristics (h) and (i) will be taken up in this course under multi-input comparator circuits.

The following points may be noted by the reader:

When only single term quantities are compared (corresponding to the current and voltage at the relay location), the resulting characteristic is either a straight line through the origin or a circle with its center at the origin depending on whether it is a phase or amplitude comparison and whether the characteristic is plotted on impedance or admittance plane. If one quantity is compared with the sum of the two quantities, the circle passes through the origin and the straight line does not pass through the origin. If there are two current terms and one voltage term or two voltage terms and one current term, neither the circle nor its straight-line dual passes through the origin. Circular characteristics passing through the origin on the admittance diagram becomes straight lines off the origin on the admittance diagram and vice versa.

Complex Characteristics (Item 'g' of the types given in Fig3.3- 16-f).

- i) MHO relay with positive and negative offset
- ii) Restricted directional relay
- iii) Restricted reactance relay iv) Restricted mho relay.

Out of the above, nos. (ii) and (iv) have been derived as special cases of the directional, reactance and mho relays respectively. We will briefly discuss them.

MHO BELAY WITH POSITIVE AND NEGATIVE OFFSET

This is only a general case of the normal type of mho relay used in practice with a negative offset. As known, this has a circular characteristic with the center not coinciding with the origin in the complex impedance plane and was referred to as

offset impedance characteristic. In practice this characteristic can be obtained by using an additional replica impedance Z_o . The offset is negative if the circle encloses the origin and positive if the origin is outside the circle. This characteristic is shown in Fig. 3.3-22 (a).

RESTRICTED DIRECTIONAL RELAY (L)

This is variation of the normal directional characteristic, such that it is a characteristic with the straight line bent at the origin i.e. the zone of operation is less than 180° , with inputs remaining the same as in a normal directional relay.

This is shown in Fig 3.3-22(b).

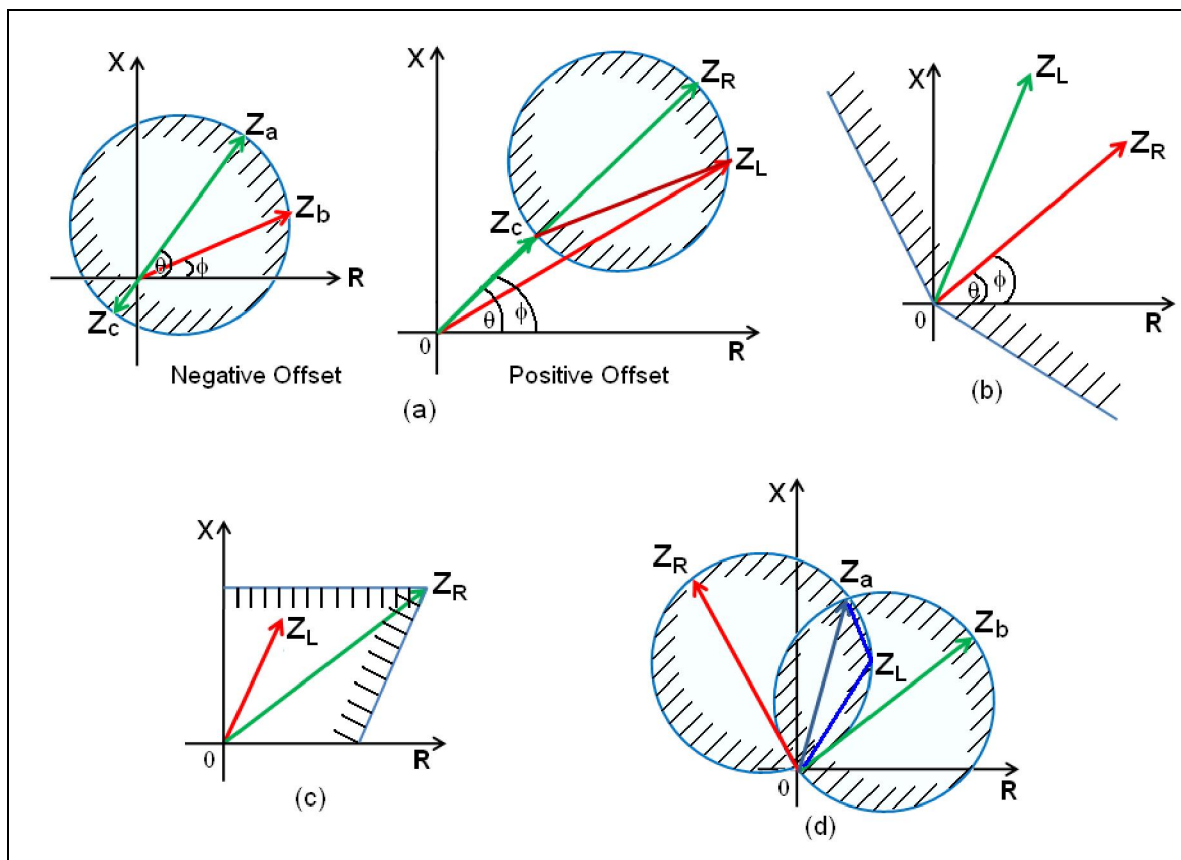


Fig 3.3-22. Complex Distance Characteristics (A) Offset Mho Restricted Directional (C) Restricted Reactance (D) Restricted Mho

RESTRICTED REACTANCE RELAY

This is again a variation of the normal reactance characteristic such that it is a straight line bent at a point as shown in Fig 3.3-22(c). It can be called the image of the restricted directional characteristic. The operating zone is again less than 180

RESTRICTED MHO RELAY

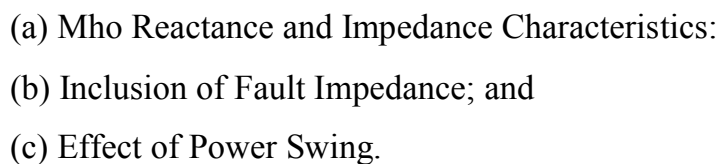
Here again this is a variation of the mho characteristic, obtained by making operating criterion other than 90° in a phase comparator giving a characteristic which is a combination of sectors of two circles as shown in Fig 3.3-22(d).

SELECTION OF THE MEASURING UNIT

The most convenient and suitable method for selecting the characteristic of the measuring relay is to represent the various conditions, such as loads, power swings, arc resistance, ground resistance as well as faults on the **R-X** diagram and then select a relay characteristic such that it operates satisfactorily under all such conditions. These are briefly stated below:

- a) The relay should operate on the desired fault up to a certain point on the line. For this the impedance vector representing the line section desired to be protected should be completely within the operating zone of the relay characteristic.
- b) Maximum loads should be permitted without tripping these points on the complex impedance plane should be outside the operating zone of the relay. Out of all the characteristics discussed, the mho characteristic will allow the maximum loads and the reactance characteristic the minimum loads for a given line length to be protected. This is shown in Fig. 3.3-23(a).
- c) The fault impedance (ground resistance and arc resistance) should have the minimum possible effects on the reach of the relay. Since ground resistance may vary considerably, a ground distance relay must be partially unaffected by large variations in the fault resistance as shown in Fig. 3.3-23(b). Consequently

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Z_R = reach with zero fault resistance

Z_f = fault resistance

Reach of reactance relay with $Z_f = Z_R$

Reach of impedance relay with $Z_f = Z_R''$

Reach of mho relay $Z_f = Z_R'$

Also $Z_R > Z_R' > Z_R''$

- d) The effect of power swings should be considered, if the line is part of an interconnected system, with synchronous systems on each end. Reactance relays are most likely to operate undesirably on large power swings unless additional blocking equipment is used. This tendency for undesired operation is minimum with mho relay and intermediate for impedance relay. This is shown in Fig. 3-23 (c).
- e) Where the distance relay has to combine the functions of directional discrimination and distance measurement, the mho relay is the most reliable as both functions are combined into one unit. The impedance relay would require a separate directional unit while the reactance relay is to be supplemented by a mho starting unit. These are shown in Fig. 3.3-24, where 3-zone protection has been illustrated with different types of relays.
- f) For different line sections, relays best suited should be selected. In some cases much better selectivity can be obtained between relays of the same type, but if relays are used that are best suited to each line section, different types on adjacent lines have no appreciable adverse effect on selectivity.
- g) Non-classical characteristics. An elliptical characteristic is better suited on power swings as it allows larger swings and also larger loads, but is more adversely affected by fault resistance. The quadrilateral characteristic has all the favorable features on power swings, fault resistance and loads and is hence considered an ideal distance relay characteristic.

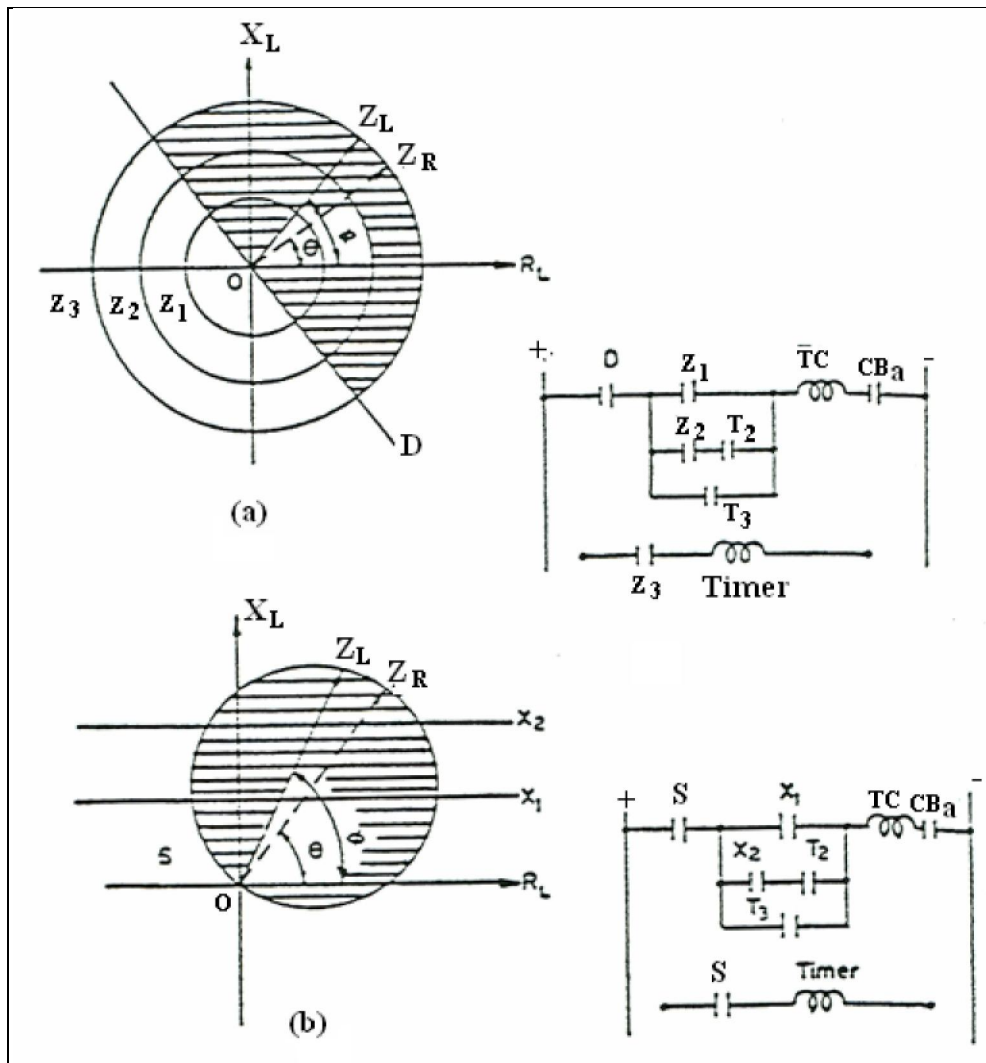


Fig 3.3-24 Three-Zone Impedance And Reactance Schemes

(a) Impedance Relays

(b) Mho Relays

VOLTAGE COMPARATOR AND CURRENT COMPARATOR:

As described earlier, the distance relay compares the ratio $\frac{V}{I}$. It is set to an

impedance $\frac{V}{I} = Z$, such that for a fault at a certain distance from relay location the relay operates if the impedance of the line, up to the fault point is less than the above relay setting Z .

The versatile family of distance includes impedance relay, Reactance relay, Mho relay discussed earlier. The measurement of impedance, reactance or admittance is done by comparison of input combination of current and voltage. Hence distance relays have input current and voltage. In static comparators the two quantities to be compared must be similar, e.g., current/current or voltage/voltage.

VOLTAGE COMPARATOR

Current I is converted into equivalent voltage V_A by producing a voltage drop in an impedance Z . The voltage drop is then compared with other voltage (Fig 3.3-25).

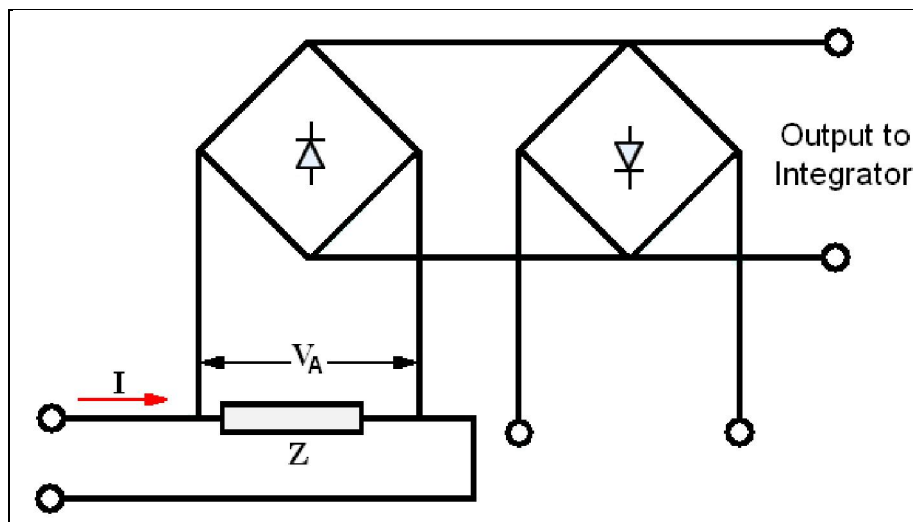


Fig 3.3-25 Distance Relay Based on Voltage Comparison Principle

BLOCK DIAGRAM OF A STATIC DISTANCE RELAY

A block diagram of a static distance relay is given in Fig 3.3-26. The line PT secondary is connected to auxiliary PT. The output of VT is converted into current. This is compared with tow output of VT.

Let us come back to Fig 3.3-25. In voltage comparator, the current is converted into voltage by passing it through impedance Z , which is the replica of the protected line section on a secondary basis. It means the IZ drop given to the rectifier bridge is compared with the line voltage V .



The current in secondary of VT corresponds to V/Z , which is compared with I . The use of replica (image) impedance permits faster tripping as it eliminates errors due to transients in fault current. This needs explanation. The transient dc component of current passing through line impedance produces a faithful voltage waveform, which is derived from line VT. The secondary current of line VT (V/Z) has faithful transient. The comparator compares V/Z and I , both having identical transient

(assuming faithful reproduction). Hence the effect of transient is cancelled out from Impedance Measurement.

The use of replica impedance reduces the influence of harmonic and transient dc components substantially.

The rectifier bridge current comparator (Fig 3.3-27) receives two current inputs, say operating input I_O and restraining input I_R . The output of comparator is applied to a permanent magnet coil relay or a static level detector.

In distance relays, I_O and I_R may be supplied either by the current transformer and by a voltage transformer through a series impedance (Fig 3.3-28) or by both sources in a particular combination to obtain particular relay characteristic.

IMPEDANCE RELAY

If restraining current I_R is supplied by voltage transformer, and operating current I_O is supplied by current transformer (Fig 3.3-28), the relay operates when the ratio V/I is less than a certain value Z_N and is therefore a minimum Impedance Relay.

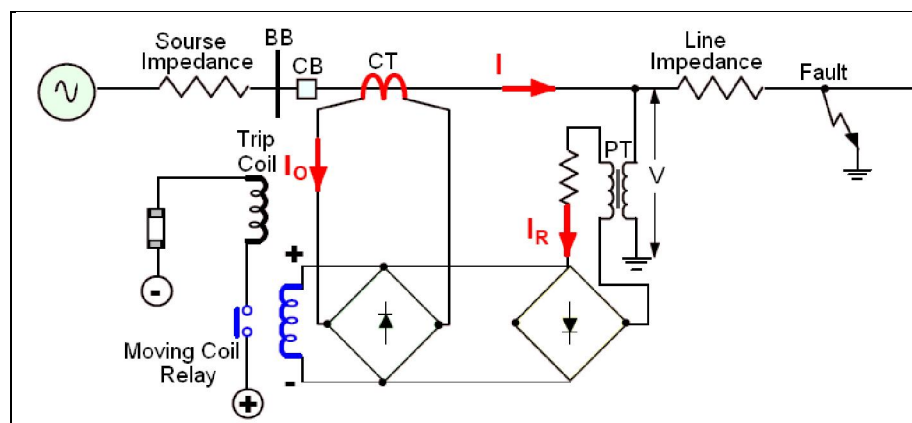


Fig 3.3-28 Comparator Used In An Impedance Relay

DIRECTIONAL IMPEDANCE RELAY

The relay operates for a particular phase-relation between V and I , restrains for some other.

In other words, the relay has Directional Characteristic.

Here directional characteristic has been obtained by a particular combination of inputs to the comparator (Fig 3.3-29) through auxiliary mixing transformer.

By the use of auxiliary mixing transformer, combination of inputs, replica impedances, dummy impedances input to comparators, a variety of characteristics can be achieved. These are called Mho, offset mho, elliptical, quadrilateral characteristics.

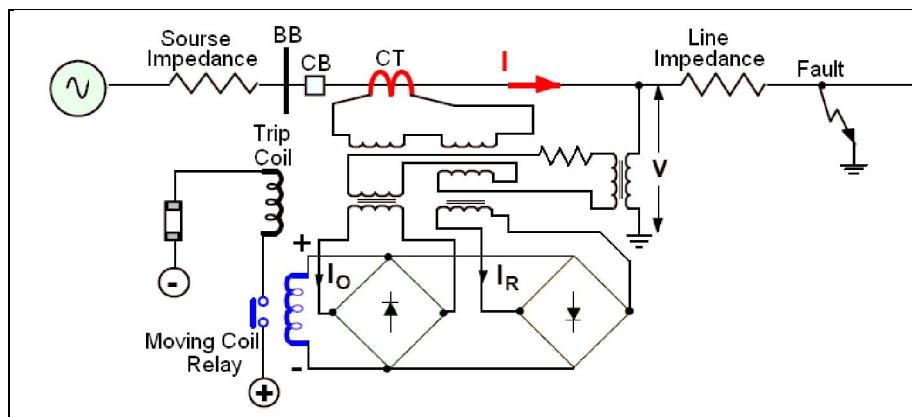


Fig 3.3-29 Comparator Used As A Directional Relay

MULTI INPUT COMPARATORS;

Distance relays can be either single phase or poly-phase and employ multi-input comparators. Such multi-input comparators are either integrating or instantaneous type and compare either amplitude or phase or both.

The characteristics of conventional double input comparators is in form of circles or sectors of circles on R-X plane. Multi-input comparators can have elliptical, conical or quadrilateral characteristic on R-X plane.

THREE-INPUT AMPLITUDE COMPARATOR:

Fig 3.3-30 illustrates a current comparator with three inputs. It is an amplitude comparator. It comprises three rectifier-bridges. The three bridges get the inputs derived from output VT, CT and mixing transformer. The voltage should be

11 17' 11 17'

Z' is replica impedance in the relay,

K is the constant to be selected.

$$x_1 = 1 \quad x_2 = 7 \quad x_3 = 1 \quad x_4 = 1$$

$$(Z - Z') + (Z - KZ') - KR = 0$$

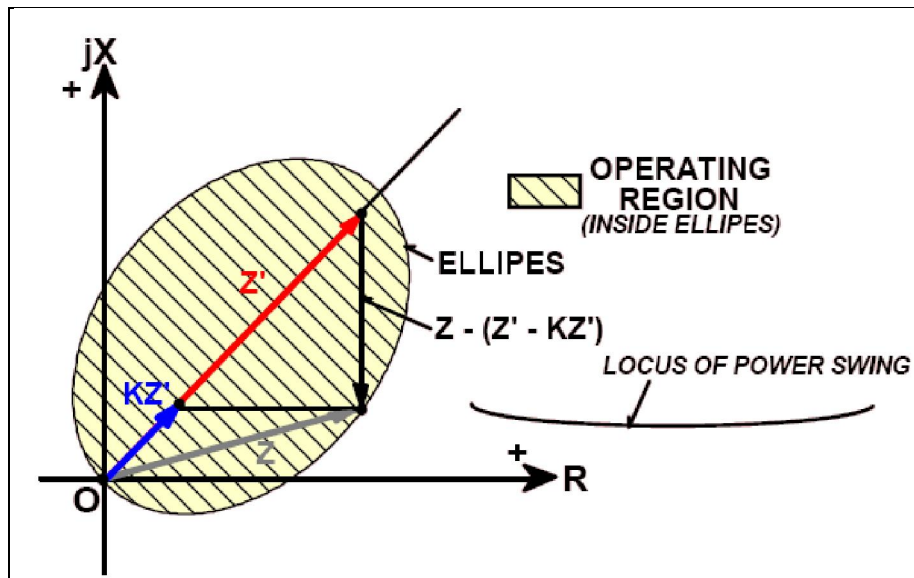


Fig 3.3-31 Characteristic of Three-Input Comparator

It is an ellipse passing through origin of **R-X** diagram. The first two terms are distances of foci from the curve and the term on right side is the major diameter.

We will recall that when V/I measured by relay is beyond the characteristic, the relay does not operate. During power swings, the elliptical characteristic with narrow coverage across **R** axis liable for tripping than circular mho characteristic.

SETTING OF DISTANCE RELAYS

We will now study the setting of impedance relay and mho relay for given line parameters. The **R-X** diagram is a powerful tool for analysis. The line characteristic and relay characteristic are drawn on the same **R-X** diagram.

We will recall that the line impedance is on the primary side of CT and VT, whereas the distance relay is on secondary side. To superimpose the line characteristic on relay characteristic both should be referred to the same side, preferably the secondary side. The following are the guide-lines:

1. System quantities **V** and **I** should refer to the same phases corresponding the relay of that phase, e.g. for earth fault protection of phase **R**, the voltage and current of phase **R** will be sensed by relay.

2. Voltage and current should be considered from the location of VT and CT.
3. Coordinates off R-X diagram must be in the same units (ohms).
4. Per unit system is preferred for large systems. Direct ohmic method may be used in simple problems.

BBC TESTING UNIT TYPE QZW-415:

The BBC relay test set type QZW-415 is shown in Fig. 3.3-32. This test set has been designed for checking the settings and calibration of distance relays. It supplies the relay with three voltages and current enables the relay characteristic to be checked at two phase-angles and for all kinds of faults.

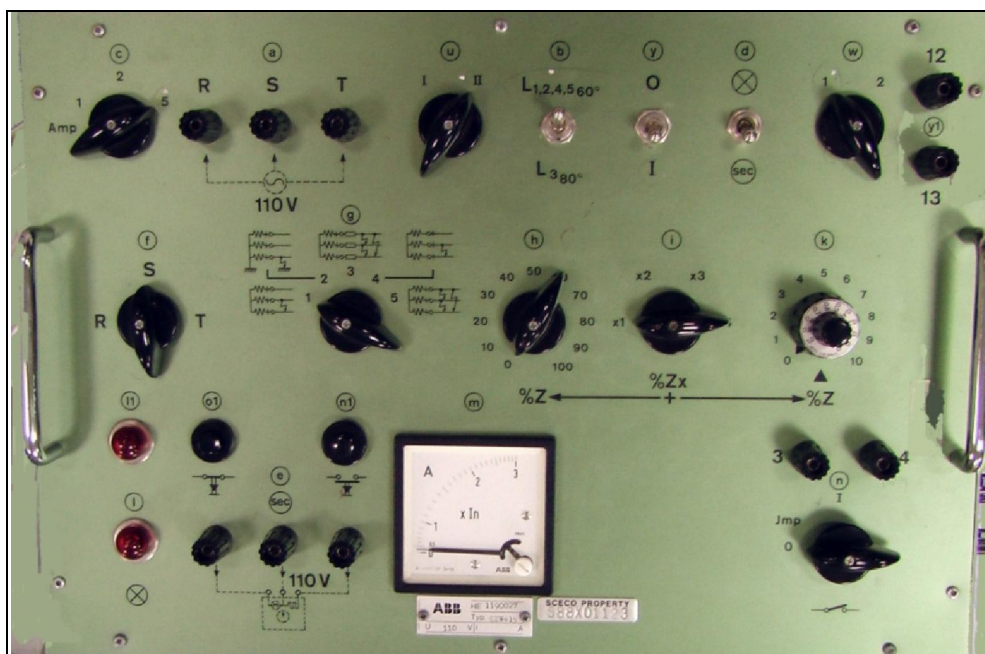


Fig 3.3-32 Relay Test Set Type QZW-415, Front View

DESIGN AND PRINCIPLE

The front panel I of the tester type QZW-415 carries all elements needed when testing distance relays as well as a changeover switch U, with the aid of which the set may be used for feeding voltage transformers allocated to the distance relay, or for feeding a separate ac source. The side panel II is used for testing current and voltage relays. By

placing the multi-way plug on the test terminals of the relay to be tested, a supply from the instrument transformers is obtained when the changeover switch U is on "I".

Supply with a corresponding external ac voltage at 110 V is effected via terminals "a" on the front panel, observing the phase sequence RST in which case the changeover switch must be turned to "II".

When the main switch n is closed (position I) an ac voltage is applied to the relay being tested and the test current can be applied by pressing button n_1 . In this case the starting unit R allows a timer to be started through potential free terminals 3-4. To stop the timer the switch Y_1 is provided (terminals 12-13). When switch y is on "d" the stop signal is isolated from the ac voltage. Button n_1 allows the memory and tripping aid of the distance relay to be tested too. For this test the short-circuit selector g must be turned to position 5 (triple pole short circuit at the point of installation). The relay can also be tested in the "impulse" position by operating the main switch n. In this case the test voltage and current are applied together. All conditions encountered when a short circuit occurs in service can be simulated; the current flowing through the test set being applied to the relay together with the voltage picked off the terminals of the choke D via a tapped voltage transformer A with the ratio 100/0.1 - 220%.

With the setting switches h, K_1 and K_2 , and with changeover switch i, the voltage supplied to the distance relay can be finely regulated between wide limits, thus enabling the pickup value of the relay to be checked. The third phase of the supply system is utilized for generating the reference voltage required when testing the directional elements of the distance relay.

The short circuit selector g applies the currents and voltages to the relay being tested, in accordance with the type of fault selected. The set is able to simulate double-pole short circuits on the line or bus bar side, short circuits also involving earth faults, as well as three-phase short circuits. The phase selector f allows phases to be changed over for asymmetric faults, with the result that the tests are comprehensive and very flexible. The simulated fault currents are constant and, on positions %Z x 1 and

$\% Z \times 2$ as multiplication factor for the impedance, are about twice the rated current of the relay being tested.

Resistor G produces a low voltage for testing the sensitivity of the relay to the direction of flow of power, while voltage transformer C is used to generate a voltage triangle to create the impression of a three-phase short circuit. The ammeter m is in series with the primary winding of the current transformer B and indicates the current being fed to the relay.

A further ammeter can be connected to the external terminals of the distance relay, being thus direct in the current circuit.

The tripping pulse emitted between terminals c_7 and c_9 is applied to the tripping contactor of the distance relay when the multi-way connector is attached to the terminals. An electric timer can be connected to the external terminals e and v, in which case the changeover switch d has to be turned to "sec.". When testing without a timer the indicator lamp 1 is switched on by the relay tripping contact when the changeover switch is on X. Switch y is used to disconnect the test terminals c_7 and a_9 (tripping circuit) from the test set so that the tripping of the breaker can also be checked when the test set is connected.

APPLICATION ON STATIC DISTANCE RELAYS (LZ-92)

INTRODUCTION

The solid-state distance relays LZ92 have been designed for high-speed discriminative protection applications, primarily in medium-voltage systems. They are equally suitable for cable and overhead line circuits and the power systems may be ungrounded, impedance or solidly grounded.

When protecting extremely short lines, the distance relays are already equipped with the logic to operate in a directional comparison scheme (permissive overreaching transfer tripping) with pilot wires.

The relays are of the switched type, having starting units (fault detectors) which apply the correct fault quantities to a single direction and distance determining measuring system.

The starting units of the LZ92 are true under impedance units (not just voltage-controlled over current) and are thus capable of detecting weak faults at times of low generation with fault currents below the maximum load currents at peak periods.

MECHANICAL DESIGN:

The distance relays comprise the following plug-in units:

- input transformer unit type **EW91**,
- signal conditioning circuits,
- measuring sockets
- auxiliary tripping relay.
- main processing unit : **KZ91**,
- signaling unit **AV94**
- auxiliary supply unit **NF92** ,a **DC/DC** converter for generating the internal relay supply voltages.
- test socket connector **XX91**.
-

DETERMINING THE SETTINGS

All important settings on the distance relay LZ92 are thumbwheel switches. The corresponding setting formulas are printed on the front plate. In each case the setting in the correct dimensions is obtained by inserting the number indicated on the thumb wheel switches in the formula and working it out.

The settings (e.g. impedance of the under impedance starting units) are printed in italics.

Settings, which are normally only made once during commissioning, are miniature switches located on the PCB's. Information relating to these settings is marked on the front plate of the KZ91 behind the hinged flap of the equipment rack. A symbol shows on which PCB the particular functional switch is to be found. The PCB's in the unit KZ91 are numbered from left to right seen from the front and as marked on

UNDER IMPEDANCE STARTING

- The pick-up of the neutral current element
- The reach of the under impedance elements.

1. NEUTRAL CURRENT EARTH FAULT DETECTOR

- The criterion for the highest setting is:
- The earth fault detector must pick up for all earth faults in grounded systems, respectively all cross country faults in ungrounded or impedance grounded systems which lie within the set reach of the under impedance units.
- The criterion for the lowest setting is:
- The earth fault detector may not pick up for an earth fault on a single conductor of an ungrounded or impedance grounded system.

The earth fault detector may not pick up during heavy phase faults due to spurious neutral currents caused by CT errors.

A typically recommended value is $I_{\Sigma} = 0.8 \text{ to } 1.0 \times I_n$ for LZ92

If there is no setting, which satisfies both these limits, a neutral voltage polarizing ancillary must be added to operate in conjunction with the neutral current element:

This is available as a separate voltage relay to be inserted into the equipment rack of the distance relay. The **LED** signal labeled "E" will only light up when both the earth fault detector and at least one under impedance phase element have picked up.

2. REACH OF THE UNDER IMPEDANCE ELEMENTS

The under impedance starting characteristic is a circle with its center at the origin of the impedance Plane.

The reach for radial lines and the different kinds of faults is:

- phase-to-phase fault: same as setting
- three-phase fault $(2/\sqrt{3}) \times \text{setting}$
- earth fault $\{ 2/(1 + K_{OL}) \} \times \text{setting}$ ($k_{OL} = K_O$ of the line)
- Minimum-Reach-of-The Under Impedance-Starting Elements

The starters must reliably pick up for a fault at the end of the next section of line (back-up zone). Where the backup zone is not being taken specifically into account, the setting must be set 1.3 times the impedance of the protected line. The influence of arc resistance must also be considered in the case of short lines.

MAXIMUM REACH OF THE UNDER IMPEDANCE STARTING ELEMENTS

The considerable increase of load current, which can occur on the healthy line when one line of double circuit is tripped, must be taken into account. Balancing currents I_A in the healthy phases during an earth fault must not cause their starters to pick up.

The limits can be expressed mathematically as follows:

* in grounded systems

$$Z = \frac{U}{2|I_{\max} + I_A|} \Omega / \text{Phase}$$

* in ungrounded or impedance grounded systems

$$Z = \frac{U_V}{2(I_{\max} \times 1.25)} \Omega / \text{Phase}$$

Where:

U	Lowest phase-to-neutral voltage of the healthy phases for an earth fault ($U = 0.85 \times \text{min. rated voltage}$)
U_V	lowest phase-to-phase rated voltage
1.25	safety factor

Extreme-Forwards Reaches

Values of X_A / X_B greater than 1 are of consequence when an extreme forwards reach is needed.

This is achieved by reversing the primary current connections to the distance relay and then reversing the measuring direction of the distance unit $I \leftrightarrow$ on the front of PCB 8.

The forwards reach then corresponds to the front plate setting multiplied by the set ratio X_B / X_A .

3. EARTH-FAULT REACH

The reach for earth faults corresponds to the front plate setting of K_O factor for the starting units matches that of the line ($K_{OA} = K_{OL}$).

The starter K_O is set using resistor Wi5 on PCB 2 in KZ91 Figure 21.

The above changes may be used singly or in conjunction with each other.

K_O FACTOR FOR THE DISTANCE MEASURING SYSTEM

The compensation of the zero sequence impedance is calculated from the positive-sequence impedance Z_L and zero sequence impedance Z_{OL} of the cable or the line.

This zero-sequence compensation factor k_0 is set on the front of the EW91 as follows:

91 code K_O : only the magnitude of K_O is set.

This is generally all that is necessary in the case of overhead lines (thumbwheel switch to zero).

91 code K.I: Both the magnitude ($|k_o|$) and phase-angle (ϕK_o) are set, which is of consequence above all in cable system.

The K_o factor only bears an influence on the distance measuring system.

IMPEDANCE SETTINGS OF THE VARIOUS ZONES

1. Determining the reaches of the distance zones

In order to calculate the settings; the fault impedances and the phase-angles of the sections of line to be protected must be known.

$$\begin{aligned} Z_1 &= 0.85 \cdot a \\ Z_A &= 1.2 \cdot a \\ Z_2 &= 0.85(a + k - b_1) \\ Z_3 &= 0.85(a + k - b_2) \end{aligned}$$

Where:

Z_1, Z_2, Z_3, Z_A zone impedances

$k > 1$ factor which takes an intermediate infeed and the consequential increase in the impedance measured by the relay into account.

a, b corresponding line impedances

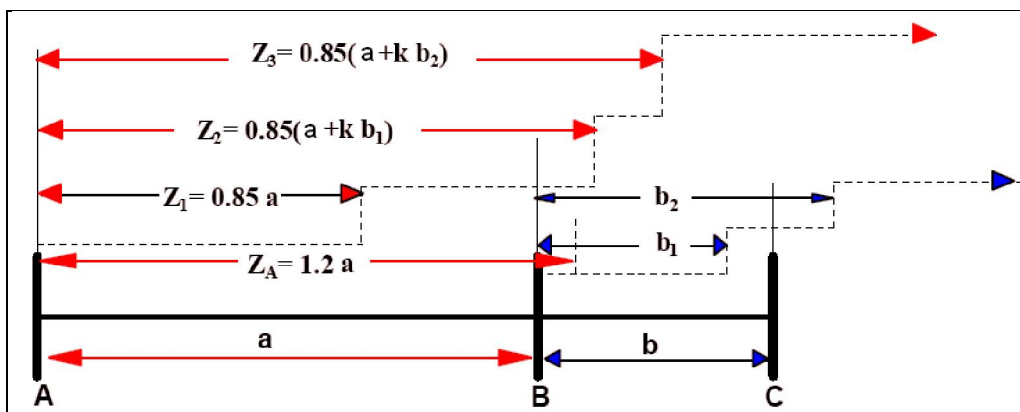


Fig 3.3-33 Reaches Of the Various Distance Zones

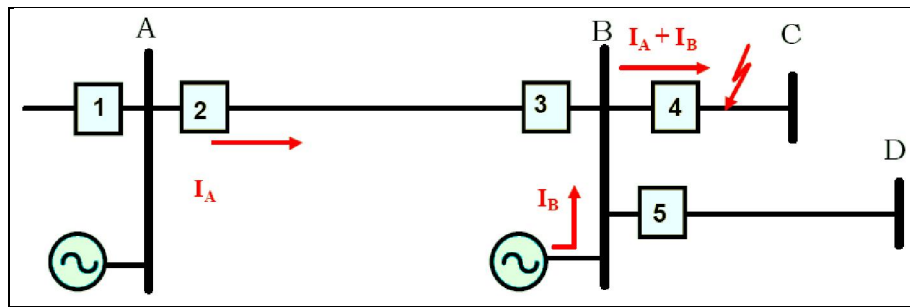


Fig 3.3-34 Example for the Calculation Of K

$$k = (I_A + I_B) / I_A \geq 1$$

Where

I_A max. possible fault current

I_B min. possible fault current 1 to 5 relays

DETERMINING THE SETTINGS M, AND NI

Secondary line impedances

$$Z_L = Z_{LP} / (V_{TR} / C_{TR}) = Z_{LP} / Z_{TR}$$

Where

Z_{LP} primary line impedance

Z_{LS} secondary line impedance

V_{TR} main PT ratio

C_{TR} main CT ratio

Z_{TR} impedance ratio

The secondary resistance and reactance values are calculated in the same manner.

• Calculating Xi:

Before the values m_i and N_i can be set on the main processing unit it is necessary to calculate X_i .

These are not exactly equal to the line reactance's X_L (line impedance $Z_L = R_L + jX_L$), because of the inclination of the relay reactance characteristic by the angle α .

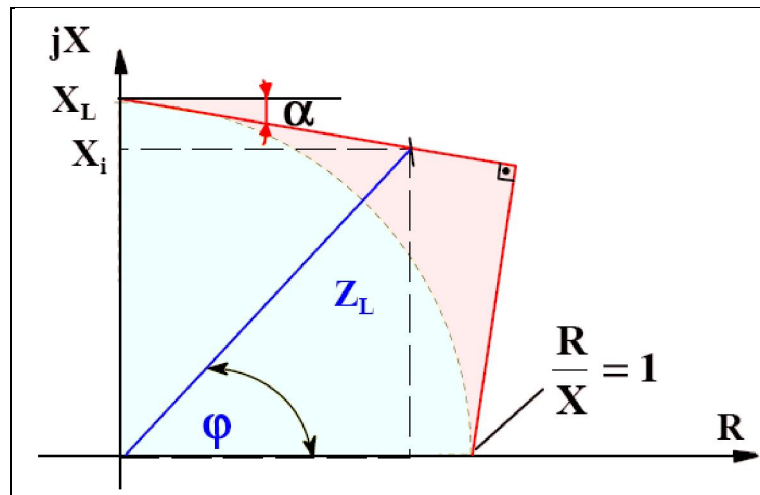


Fig 3.3-35 Line Impedance Z_L Entered In the Relay Characteristic

φ	K_X	K_R
0	-	1
5	-	0.992
10	-	0.985
15	-	0.977
20	-	0.968
25	-	0.959
30	-	0.95
35	-	0.939
40	1.104	0.927
45	1.087	-

φ	K_X	K_R
50	1.073	-
55	1.061	-
60	1.05	-
65	1.041	-
70	1.032	-
75	1.023	-
80	1.015	-
85	1.008	-
90	1	-
		-

Table 3.3-3 Factors K_X and K_R In Relation To φ ($\alpha = 5^\circ$)

The reactance's X_i the line reactance's have to be corrected by the factor k_x :

$$X_i = X_{Li} \times K_x$$

The correction factor k_x is given by:

$$K_x = 1 + (\tan \alpha / \tan \varphi).$$

If the phase angle φ is less than 40° as can be the case in cable systems, the polygon can be set in relation to the line resistance. The arc resistance compensation R/X is then set to 1.

When $\varphi_L < 40^\circ$

$$X_i = k_R \times R_{Li}$$

Where $k_R = 1 - (\tan \infty \cdot \tan \varphi)$

For grading the relay settings R_{Li} is used instead of X_{Li} and R instead of K_X .

Example 3.3-1

- System voltage : $U = 60 \text{ kV}$
- PT. ratio : $K_U = (60 \text{ kV} \sqrt{3}) / (110/\sqrt{3}) = 545.45$
- CT ratio : $K_I = 200 \text{ A} / 5 \text{ A} = 40$
- Primary zone impedances $Z_{LP1} = 4 \Omega$,
- $Z_{LP2} = 6 \Omega$,
- $Z_{LP3} = 8 \Omega$
- Phase-angle of line $\varphi = 60^\circ$
- Relay ratings $I_n = 5 \text{ A}$, $U_n = 110 \text{ V}$
- Reactance line slope $\infty = 5^\circ$

Calculate the reactance “X” for each zone.

Solution:

Firstly the secondary reactance's must be calculated from the primary values:

$$X_{LS} = X_{LP} \cdot (C_{TR}/V_{TR}) \text{ and } X_{LP} = Z_{LP} \times \sin \varphi$$

The line reactance's for the three zones become:

$$X_{LP1} = Z_{LP1} \times \sin \varphi = 4 \times \sin 60^\circ = 3.464 \Omega$$

$$X_{LP2} = Z_{LP2} \times \sin \varphi = 6 \times \sin 60^\circ = 5.196 \Omega$$

$$X_{LP3} = Z_{LP3} \times \sin \varphi = 8 \times \sin 60^\circ = 6.928 \Omega$$

$$X_{LS1} = X_{LP1} \times (C_{TR}/V_{TR}) = 3.4640 \times (40 / 545.45) = 0.254 \Omega$$

$$X_{LS2} = X_{LP2} \times (C_{TR}/V_{TR}) = 5.196 \times (40 / 545.45) = 0.381 \, \Omega$$

$$X_{LS3} = X_{LP3} \times (C_{TR}/V_{TR}) = 6.928 \times (40 / 545.45) = 0.508 \, \Omega$$

The correction factor K_X is :

$$K_X = 1 + (\tan 5^\circ / \tan 60^\circ) = 1.05$$

The zone reactance's X can be calculated now:

$$X_i = X_{Li} \times K_X$$

$$X_1 = 0.254 \times 1.05 = 0.267 \, \Omega,$$

$$X_2 = 0.381 \times 1.05 = 0.4 \, \Omega,$$

$$X_3 = 0.508 \times 1.05 = 0.533 \, \Omega$$

CALCULATING THE SETTING FACTORS M_i AND N

The factors m_i and N_i can be calculated from the following formula:

$$X_i = (H/I_n) \times m_i \times (100/N_i) \quad (1)$$

Where:

H : factor depending on the rated voltage

$H=1$ for $U_n = 100$ to $130 \, V$

$H=2$ for $U_n = 200$ to $260 \, V$

I_n relay rated current $1 \, A, 2 \, A, 5 \, A$

m_i impedance measuring range (see Table 4)

N_i percentage" impedance setting for the distance zones

i index denoting the distance zone, ($i = 1$ for zone-I etc)

The setting range m_i can be set individually for each of the zones on the front plate of the KZ91.

Switch m_i . setting	I	II	III
m_1	0.1	0.5	5
m_2 or m_3	0.1	1	10

Table 3.3-4 Values of the factor m for zones 1 to 3
represented by the settings of switch m_i

The percentage N can also be set from 0 to 99 in steps of 1 individually for each zone. The m setting should permit N to be set as accurately as possible, i.e. the value of I_n should be as high as possible.

An N of 100 is therefore inserted initially in order to determine the best setting range m.

From (1) with $N = 100$: $m_i = X_i / (H/I_n)$

The value of m obtained in this way is then rounded to the smaller value s given in table 4

By inserting this value of m in equation (1) the actual N setting can now be obtained.

$$\therefore N_i = \frac{H}{I_n} \times \frac{m_i}{X_i} \times 100, \quad X_1 = 0.267 \, \Omega, \text{ \& } X_2 = 0.4 \, \Omega, \quad X_3 = 0.533 \, \Omega,$$

Ratings factor $(H/I_n) = 0.2$ with $H = 1$ for $U_n = 110 \, \text{V}$ and $I_n = 5 \, \text{A}$

Measuring range: m_i :

$$\therefore m_i = X_i / (H/I_n)$$

Therefore

$$m_1 = 0.267 / (0.2) = 1.34 \text{ rounded to } m_1 = 0.5 \quad (\text{see Table 4})$$

$$m_2 = 0.4 / (0.2) = 2 \text{ rounded to } m_2 = 1 \quad (\text{see Table 4})$$

$$m_3 = 0.533 / (0.2) = 2.665 \text{ rounded to } m_3 = 1 \quad (\text{see Table 4})$$

$$\therefore N_i = \frac{H}{I_n} \times \frac{m_i}{X_i} \times 100$$

$$\text{Percentage settings} \quad N_1 = 0.2 \times (0.5/0.267) \times 100 \approx 38$$

$$N_2 = 0.2 (1/0.4) \times 100 = 50$$

$$N_3 = 0.2 (1/0.533) \times 100 \approx 37$$

MAIN PROCESSOR UNIT SETTINGS

Thumbwheel switch $m_1 =$ II, $m_2 =$ II and $m_3 =$ II

Thumbwheel switch $N_1 =$ 38, $N_2 =$ 50 and $N_3 =$ 37

ARC RESISTANCE COMPENSATION

The ratio R/X can be set between 1 and 5 in steps of 1 on a control on the front of the main processing unit. The actual setting depends on the value of arc or earth resistance to be expected in relation to the reactance of the line.

Typical settings for overhead lines; $R/X = 1, 2$ or 3 . A setting of $R/X = 1$ is permissible in cable systems, since high arc resistance are not to be expected. Where the phase-angle of the positive-sequence impedance is less than 40° the ratio R/X is set to 1 and the RL is used for grading the relays. According to van C. Warrington arc resistance can be calculated from:

$$R_{\text{arc}} = 28700 d / (I \times 1.4)$$

Where

d	length of the arc in m
I	current in A
R_{arc}	arc resistance in ohms

In the impedance plane it can be seen that the influence of arc resistance varies with the kind of fault, because the unit is ohms per phase. A given fault resistance R_F in the R/X plane is as follows:

- earth fault : $R = R_F / (1 + |k|)$ (for overhead lines)
- phase-to-phase fault : $R = R_F / 2$

In grounded systems R , will be greatest for an earth fault.

For a given line impedance $Z_L = R_L + jX_L$ the required arc resistance compensation

thus becomes:
$$\frac{R}{X} = \frac{(R_L + R)}{X_L}$$

DIRECTION OF MEASUREMENT

The directional sensitivity of the LZ92 is 100 mV ($U_n = 100$ to 130 V).

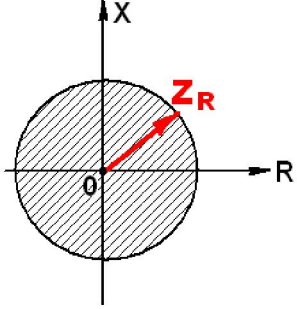
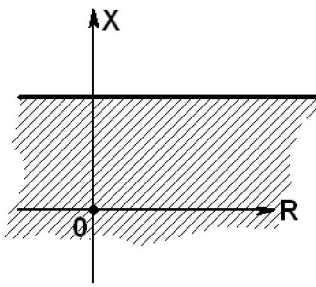
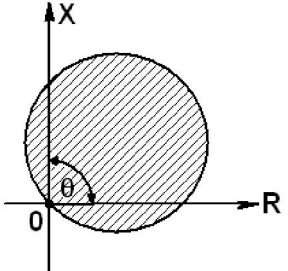
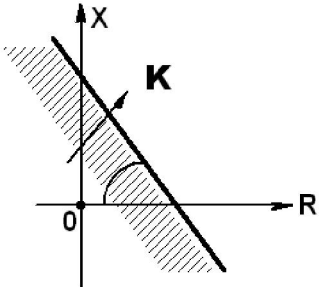
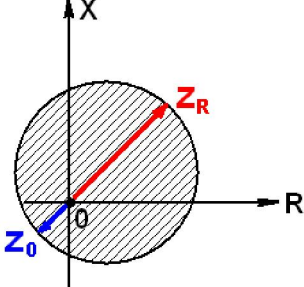
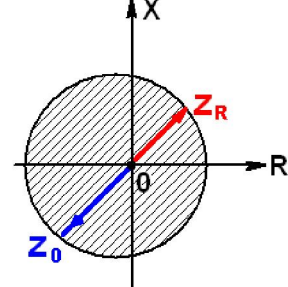
Zone 4:

Normally the operating characteristic of zone 4 is that of the starting unit, which is permitted to trip on its own after the time t_4 .

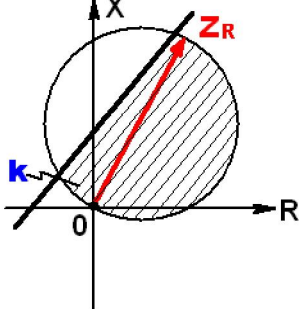
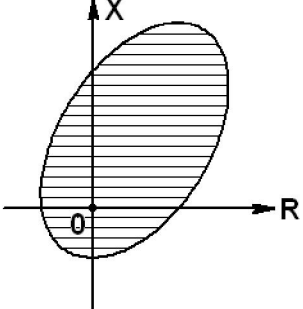
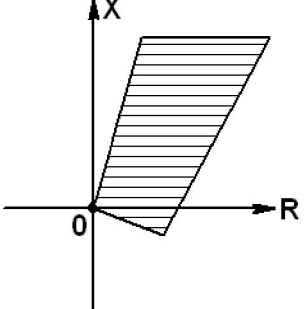
Non-directional operation means that the whole of the starting characteristic is used for zone 4, compared with directional operation with the starting characteristic cut off by the directional measurement so that tripping can only take place in the forward direction.

SUMMARY

- The distance relay operates essentially by comparing phasors of voltage and current. In solid-state relay, as the circuits are interconnected, the two inputs must be converted to the same units, either either voltage or both current.
- For a voltage comparator relays, the current is passed through a replica impedance Z , which is tuned to the same value as the line. The voltage drop across this impedance $I \times Z$ is then fed into the amplitude comparator to be compared with the polarizing voltage from the line.
- For a current comparator relays, the VT voltage signal is applied across the replica impedance so as to produce proportional current, the equivalent current values are compared.,.
- Sequence comparator is used in static distance relays for precise controlling and relay. The two sinusoidal quantities (polarizing voltage " V_p " and the vectorial difference of measured line voltage V minus the voltage drop to the fault, " IZ "), are fed into the sequence comparator, which converts them to a square wave and then compares the logic sequence
- The polarizing voltage, V_p is arranged to lag the line voltage V by 90° .
- Types of Distance Relays:

		
a) Impedance Relay	b) Reactance	c) Mho or Admittance (Angle Admittance)
		
d) Ohm (Angle Impedance)	e) Offset Mho	f) Modified Impedance

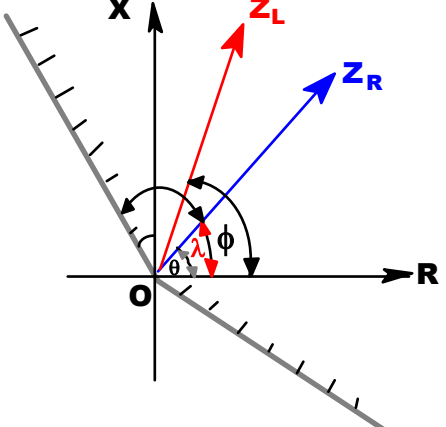
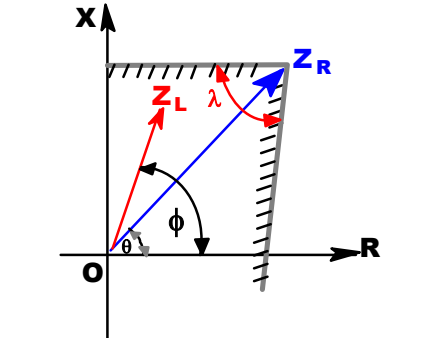
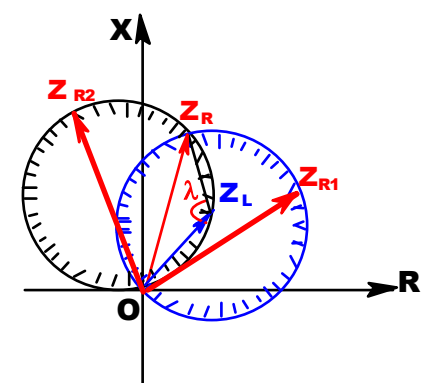
Classic Characteristics Types

		
g) Complex Characteristics	h) Elliptical Characteristics	i) Quadrilateral Characteristics

Non-Classical Characteristics Types

- Mho Relay with Positive and Negative Offset has a circular characteristic with the center not coinciding with the origin in the complex impedance plane and was referred to as offset impedance characteristic.

- Mho Relay characteristic can be obtained by using an additional replica impedance Z_o . The offset is negative if the circle encloses the origin and positive if the origin is outside the circle.

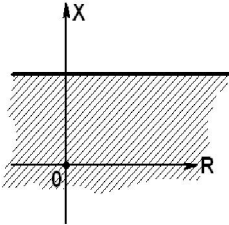
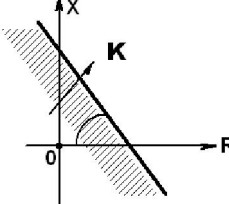
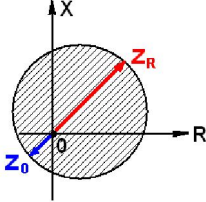
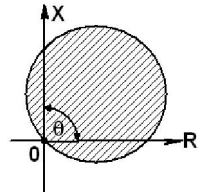
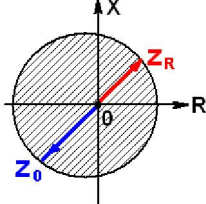
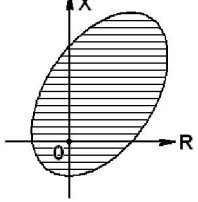
<ul style="list-style-type: none"> • Restricted Directional Relay has a variation of the normal directional characteristic, such that it is a characteristic with the straight line bent at the origin i.e. the zone of operation is less than 180°, with inputs remaining the same as in a normal directional relay 	
<ul style="list-style-type: none"> • Restricted Reactance Relay has a variation of the normal reactance characteristic such that it is a straight line bent at a point as shown. It can be called the image of the restricted directional characteristic. 	
<ul style="list-style-type: none"> • Restricted Mho Relay has a different mho characteristic, obtained by making operating criterion other than 90° in a phase comparator giving a characteristic, which is a combination of sectors of two circles as shown . • When the angle is $\pm 90^\circ$ the sectors become semi-circles, when it is less than 90°, the sectors are larger than semi-circles, while it is more than 90°, they are smaller than semi-circles 	

RELAY TYPES	APPLICATIONS
Reactance relays	<ul style="list-style-type: none"> • are generally preferred for ground relaying • preferred for very short line sections phase-fault relaying • operate undesirably on large power swings unless additional blocking equipment is used • Additional mho starting unit is required for distance relays that required to combine the functions of directional discrimination and distance measurement
Mho relays	<ul style="list-style-type: none"> • preferred for long lines • undesired operation is minimum on large power swings • the most reliable for distance relays that required to combine the functions of directional discrimination and distance measurement
Impedance relays	<ul style="list-style-type: none"> • the best for moderate lengths • undesired operation is intermediate on large power swings • require a separate directional for distance relays with combined functions of directional discrimination and distance measurement
elliptical characteristic	<ul style="list-style-type: none"> • is better suited on power swings as it allows larger swings and also larger loads, but is more adversely affected by fault resistance.
quadrilateral characteristic	<ul style="list-style-type: none"> • Has all the favorable features on power swings, fault resistance and loads and is hence considered an ideal distance relay characteristic.

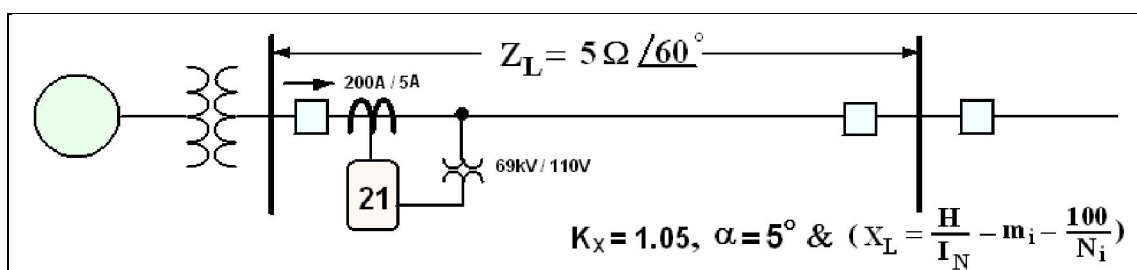
- In distance relays measurement of impedance, reactance or admittance is done by comparison of input combination of current and voltage. Hence distance relays have input current and voltage.
- In static comparators the two quantities to be compared must be similar, i.e.
 1. current to current or
 2. Voltage to voltage.

REVIEW EXERCISE

Match between Column A B in the following table

A	B
1. Impedance Relay	I 
2. Reactance	II 
3. Mho or Admittance(Angle Admittance)	III 
4. Ohm (Angle Impedance)	IV 
5. Elliptical Characteristics Type	V 
6. Offset Mho	VII 

7. The polarizing voltage V_p of sequence comparator, in static distance relays is arranged to _____
- a) Lead the line voltage V by 90° . b) In phase with the line voltage by 90° .
c) Lag the line voltage V by 90° . d) Out of phase with the line voltage
8. The distance relay operates essentially by comparing phasors of _____ voltage and current. In solid-state relay, as the circuits are interconnected, the two inputs must be converted to the same units, either both voltage or both current _____
- a) voltage and current
b) voltage and voltage
c) current and current
d) voltage and impedance
9. In solid-state distance relay, as the circuits are interconnected, the two inputs must be converted to the same units, either _____
- a) both impedance or both admittance
b) both resistance and both reactance
c) both analog and both digital
d) both voltage or both current
10. Referring to given T.L. data shown below, if we use LZ92 static distance relay find.:
- a. M1, M2 and M3 (impedance measuring ranges)
b. N1, N2 and N3 (percentage setting)
c. ARC resistance compensation



Match the between the following Columns, then fill the next table:

11. . Impedance relays	A. preferred for very short line sections phase-fault relaying
12. quadrilateral characteristic	B. the most reliable for distance relays that required to combine the functions of directional discrimination and distance measurement
13. Mho relays	C. require a separate directional for distance relays with combined functions of directional discrimination and distance measurement
14. elliptical characteristic	D. is better suited on power swings as it allows larger swings and also larger loads, but is more adversely affected by fault resistance.
15. Reactance relays	E. has all the favorable features on power swings, fault resistance and loads and is hence considered an ideal distance relay characteristic.

11	12	13	14	15

REVIEW EXERCISE

16. State 5 advantages for static distance relays.

17. State the disadvantages for static distance relays.

TASK 3.3-1

TESTING STATIC DISTANCE RELAY

OBJECTIVES

Upon completion of this task, The trainee will be able to perform all type of the required tests on the Static distance relay .with a high accuracy and with a tolerance permitted in the instructional manual.

TOOLS AND EQUIPMENT

- Distance relay type LZ92
- Test set
- DC power supply (to suit relay auxiliary voltage 110V).
- Relay technician tool kit.

Objective 1: Testing Distance Relay Using Test Buttons

- In order to test the relay using the test buttons, load voltages must be applied and a load current in excess of $0.2 \times I_n$ must be flowing.
- Pressing a starter test button simulates a fault on the corresponding phase or phases.

CHECKING THE DIRECTION OF MEASUREMENT:

As soon as one or more of the test buttons (R, S or T) are pressed the corresponding starting unit or units pick up and the auxiliary tripping relay is interlocked to prevent operating the circuit - breaker inadvertently. The starting units apply phase quantities to the measuring unit according to the kind of fault being simulated. The relay will pick up in some stage or other depending on the load current at the time and Relay settings. (If the values and phase -angle of the load quantities is known, it is even possible to test the various zones by suitably changing the settings.)

Providing the fourth zone is non-directional, the relay must at very least pick-up in the fourth zone (red LED lights up). The fourth zone must be made directional and all the zones be measuring in the forwards direction in order to check the relays ability to determine direction. The corresponding switch positions are: switch 8a in position 1, switch 8b in position 1 or 2 depending on input transformer connection and switch 7 in position 1.

CAUTION!

Units may only be withdrawn from the rack when the auxiliary supply is switched off.

Under the above conditions the relay must pick up when the load energy is flowing in the forwards direction and block when the energy direction is reversed by operating switch Bb (part number HESG 439 686) or the front plate switch I ' (part number HESG 440 718), or vice versa. The ability of the relay to pick up and block must be tested in this way for all kinds of faults. Withdrawing a relay with non-directional fourth zone can be avoided by setting the thumbwheel switch N of the corresponding zone to 0% (infinite reach).

Should the direction be incorrect for a particular kind of fault, the polarity of all CT's, PT's, leads and connections must be checked (see Sections 5.3 and 5.4). If the direction is incorrect for all kinds of faults, all the current connections must be reversed.

Objective 2: Testing Tripping Circuit

On the input transformer unit EW91 apply a signal manually to the auxiliary tripping relay and thus trip the circuit-breaker. This operation, however, is interlocked for safety reasons.

1. Firstly, terminal E-II of the input transformer unit must be connected to terminal E-63 of the main processing unit.
2. Then the sockets must be connected.
3. Finally a starting button must be pressed.

It is not possible to test the tripping circuit, if the connection EII-E63 is not made.

Objective 3: Testing Distance Relay Using Test Set

Providing the relay is equipped with a test socket XX91, a test set can be simply connected by means of the test connector YX91. As soon as the test connector is inserted, a signal is emitted (providing it is appropriately wired via an auxiliary signaling relay in the unit AV91 respectively AV92) to indicate that the relay is no longer standing by (V.0 in the code of the main processing unit).

When it is plugged in the test connector:

1. short-circuits the main CT's
2. isolates the relay input from CT's and PT's
3. interrupts the tripping circuit
4. blocks the external signals (driver outputs and signals to ancillaries) for starting,
5. Tripping and timer (where fitted) for the duration of testing.
6. connects the PT. voltages to the test set (where necessary)
7. connects the current and voltage inputs of the relay to the test set.

Facility is provided in the test connector for enabling the signal outputs for ancillary units if necessary.

A sample test report for testing with a test set can be found in the appendices.

- **Instructions For Modifying Relay Operation**

Normally the desired relay operation is defined by the ordering code. However, should changes become necessary during commissioning, then small changes (soldered link or value of a resistor on soldering posts) can be done.

Objective 4: Measuring Pick-Up Values

The positions of switch x which are given apply when the sliding switch 8b is set to 2.

Measuring system

X blinder

Switch x	zone measuring forwards	+I
	zone measuring reversed:	-I
Switch b	set to L3	corresponds to $\phi_k = 80^\circ$
	set to LI,2, 4, 5	corresponds to $\phi_k = 60^\circ$

The test current is set to $1.8 \times I_n$ using the resistor connected to **q** (ammeter on the test set).

- The test current must be greater than the setting of I_Σ : (LZ92).
- If necessary, these settings must be reduced to facilitate testing.

Now measure the zone 1, 2 and 3 pick-up values for the kinds of faults given in the test report.

This is done by increasing the values of **h**, **i** and **k** step-by-step until the relay just does not pick up in the zone being tested.

The value of % Z to be entered in the test report is the one, which the relay just picks up.

The values corresponding to the actual relay settings are calculated as follows:

- Phase-to-phase fault $g = 1$

$$\% Z_{set} = 3.57 \times 10^4 \times \left(\frac{mi}{f \times Ni} \right) \times K$$

- Earth fault $g = 2$

$$\% Z_{set} = 3.57 \times 10^4 \times \left(\frac{mi}{f \times Ni} \right) \times K \times \left(\frac{1+K_o}{2} \right) \quad \phi_{ko} \text{ set to } 0^\circ \text{ on the relay}$$

where: **k** = correction factor

generally $k = 1/(\sin \phi_k (1 + \tan \alpha / \tan \phi_k))$

switch **b** : L3 $a = -5^\circ$, $k = 1.0$

switch **b** : LI,2,4,5; $a = -50$, $k = 1.1$

f frequency

m i set reach, coarse setting on the KZ unit

N i set percentage value, fine setting on the KZ unit

index **i** denotes zone 1, 2 or 3

α inclination of the reactance blinder of the relay characteristic normally calibrated to $\alpha = -5^\circ$

R blinder

The following circuit enables a point on the resistance blinder (impedance angle 0°) to be measured:

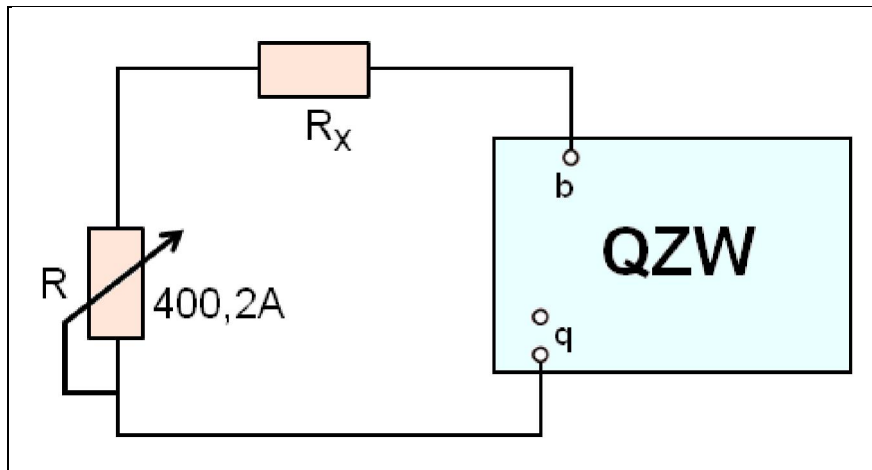


Fig. 1-1

$U_n = 110 \text{ V} : R_x = 28 \text{ ohms} \pm 1\% / 2 \text{ A}$

positive tolerances result in under reaching

switch **p**

: position E

switch **b**

: position L1, 2, 4, 5

Calculation of the set pick-up value:

- phase-to-phase faults $g = 1$

$$\% Z_{\text{set}} = 714 \times (m_i / N_i) \times (R/X)$$

- earth faults $g = 2$

$$\% Z_{\text{set}} = 714 \times (m_i / N_i) \times (R_x / X) \times \{ (1 + K_o) / 2 \} \quad \phi k_0 \text{ set on the relay to } 0^\circ$$

DIRECTIONAL MEASUREMENT

switch -p : return to I, L

switch-x : - I

switches- h, I and k : 1%

The relay may not pick up in zones 1, 2 and 3 for any of the six combinations of g & f when the button n or n1 is pressed.

Starting units are under-impedance

Test Set Switch Positions:

b :L3
x :forward starting : +I
:reverse starting : -I

Set the injection current to $1.8 \times I_n$ (ammeter on the test set) using the resistor connected to q.

The injection current for this test must be greater than I_Σ . If necessary reduce the setting of I_Σ .

• **CALCULATION OF THE EFFECTIVE SETTING FOR A CIRCULAR CHARACTERISTIC:**

a) Forwards direction:

phase-to-phase faults	$g = 1$	$\%Z = (Z \times 357) / f$
earth faults	$g = 2$	$\%Z = \{(Z \times 357)/f\} \times (1+ko) / 2$

b) Reverse direction

phase-to-phase faults	$g = 1$	$\% Z = \{(Z \times 357)/f\} \times c$
earth faults	$g = 2$	$\%Z = \{(Z \times 357)/f\} \times c \times (1+ko) / 2$

where

z setting on the thumbwheel switch "ZxH/In" on the relay

f frequency

$(1+ ko) / 2$ usually 1

c: concentric char. $c = 1$

off-set MHO (compounded) $c \neq 1$

Find the value at which the relay trips in the fourth zone upon pressing the button n l'

c) Pick-up value of the enabling unit for the under-impedance units:

Test set switch positions: **G** = 2, **i** and **c** :according to the following table:

Switch i	Aprox. Max. injection current in A C: 5A
X1	12.5
X2	6.25
X3	4.0
X4	3.0

h and **k** : 0%

link r : open, ammeter connected

Set **f** to the phase to be tested. After pressing button **n** increase the injection current using the resistor connected to **q** until the starting signal of the phase set on **f** lights up. The effective setting is approx. $0.2 \times I_n$. Pay no attention to the tripping signal, because its operation is undefined due to the test circuit.

d) PICK-UP VALUE OF THE NEUTRAL CURRENT UNIT:

The test set settings are the same as for the enabling unit with the exception that **g** is set to 2 and the setting of **f** has no influence.

Increase the injection current until the signal **E** lights up.

Objective 5: Measuring operating times

Two potentially free contacts are available for starting respectively stopping a timing instrument for measuring the operating times of the various units. Starting Contact: terminals 3 and 4 of the QZW415. Contact closes when the injection current is switched on. Stopping Contact: terminals of distance trip contacts. With switch **y** set to **0**, the contact closes when the auxiliary tripping relay operates. Time measurements are made in the same manner as described in before. The switches **h**, **I** and **k** are set to the mean values between the zone settings (e.g. half way between the setting of zone 1 and the setting of zone 2 in order to measure time t_2)

MAR 21 93 03 :12 PM SCECO-EAST HQS SSOD 8585408
P.3/4
PROTECTIVE RELAY SETTING

SUBSTATION : AWAMIAH 69 KV GRID STATION

RELAY NUMBER : S-7003

LINE : CIRCUIT # 1 TO QATIF BSP

BY:

RELAY SET : PRIMARY

DATE : MARCH 21 , 1993

APPLICATION	MANUFACTURER STYLE & RATING	SETTING
PHASE AND GROUND SWITCHED DISTANCE RELAY WITH FOUR ZONES	BBC LZ92 In = 5 A 21P	UNDER IMPEDANCE STARTERS $Z = 30 \times H \text{ In}$ $H/\text{In} = 0.2$ $H = 1$ $I_o = 3 \times 0.2 \text{ In}$ $R/X = 3$ Σ ZONE 1 $M1 = II$ (0.5) $N1 = 20 \%$ ZONE 2 $M2 = II$ (1) $N2 = 27 \%$ ZONE 3 $M3 = II$ (1) $N3 = 17 \%$ RESIDUAL COMPENSATION ANGLE $\phi = 0$ $K_o = 12 \times 0.1$ $t_2 = 40 \times 0.01 \text{ SEC}$ $t_3 = 8 \times 0.1 \text{ Kt} = 1$ $t_4 = 20 \times 0.1 \text{ SEC}$ SWITCH 1 6a 6b 7 8a 8b 1 2 2 2 1 2 SYSTEM EARTHING SWITCH SWITCH 1 2 3 4 POSITION OFF ON ON OFF

BASIS OF SETTINGS :

ZONE 1 = 0.481 ohm sec.

ZONE 2 = 0.679 ohm sec.

ZONE 3 = 1.244 ohm sec.

COMMENTS :

These settings are made for the plane Distance protection considering pilot cable and communication equipment out of service.

DRAWING NUMBER :

CT RATIO : 800 / 5 A

VT RATIO : 66000/100

CIRCUIT BREAKERS A501

STATIC FREQUENCY RELAYS

BASIC IDEAS FOR FREQUENCY RELAYS

The frequency relays either under or over frequency as well as rate of change of frequency. Fig 3.3-37 shows the basic frequency sensitive differential resonant circuit, which the output obtained, is dependent only on frequency. The difference in frequency with the sign of the difference appears as a proportional current in the output device.

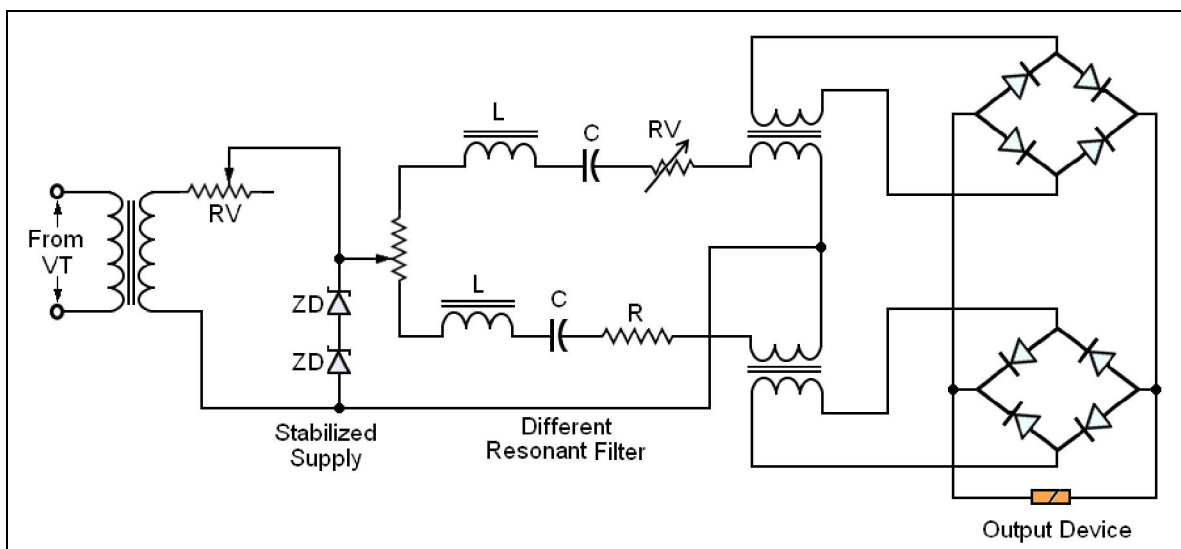


Fig 3.3-37 Frequency - Sensitive Circuit

The frequency sensitive feature is obtained by a simple **L-C** circuit shown in Fig 3.3-32(a).

The block and detailed circuit diagrams are given in Fig 3.3-38 a & b and Fig. 3.3-39.

The voltage V_O is rectified through a phase-splitter-rectifier arrangement.

Another rectified voltage V_{O1} is also obtained through phase-splitter-rectifier arrangement and a potentiometer. Now, V_{O1} is set such that at the base frequency $|V_O| = |V_{O1}|$, and no trip output is obtained.

When the frequency drops, the amplitude comparator produces an output, which triggers an alarm enunciator through a time delay circuit.

The relay can also be disconnected during a fault and starting-up period. In the case of a fault, a static fault detector consisting of a phase splitter and a differentiating circuit, can be designed to produce an output pulse to trigger a mono-stable circuit, a slave relay then removes the dc supply to the transistor circuits so that it is made inoperative. During starting-up period, the relay is prevented from operation as the dc supply to the transistor circuits is completed through a contact on the synchronizing CB.

Under normal frequency conditions, points A and B in Fig 3.3-39 are at the same potential, transistor T1 blocks and T2 and T3 are off; T4 is driven to saturation shorting the capacitor C5; T5, T6 and T7 are also off. When the frequency drops, A becomes more positive with respect to B. This voltage after overcoming the input bias, switches on T1 T2 and T3; T4 is switched off and capacitor C5 starts getting charged through R13 and R14.

This provides time delay also. When $V_{C5} > V_{C_e}$ T5 conducts switching on T6; T7 is driven to saturation energizing the alarm circuit. Pick-up adjustment is done by varying R6. Base frequency adjustment is done by R3 Time-delay is adjusted by R14

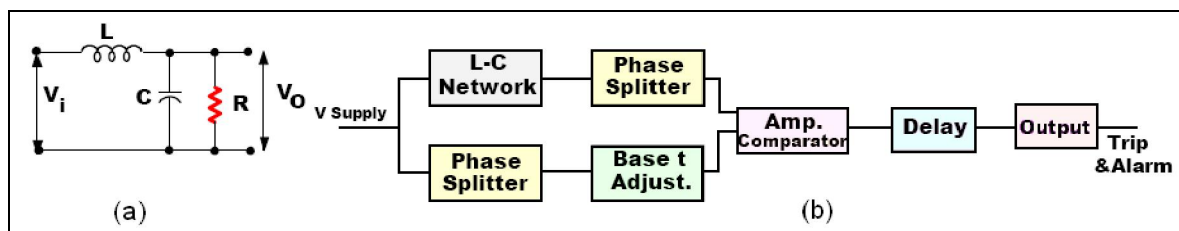


Fig 3.3-38 Over/Under Frequency Relay. LC Circuit & Block Diagram

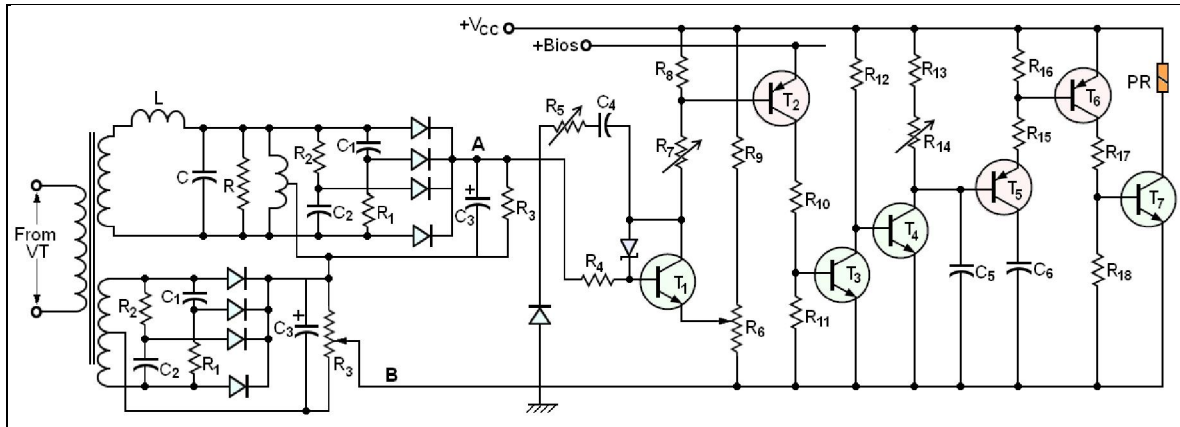


Fig 3.3-39 Over/Under Frequency Relay Detailed Circuit

The relay can be converted to an over-frequency relay by reversing the polarities of the output terminals of both phase splitters. The differential circuit gives a positive output if the supply frequency increases above normal and negative output if the supply frequency is below normal. This output is fed to Rectifier Bridge to give a positive output under both conditions. The output of Rectifier Bridge is integrated through a fin integrator and then fed to a level detector to give the trip signal.

ELECTRONIC FREQUENCY RELAY TYPE FCX103

Electronic frequency relay type FCX 103b as shown in Fig. 3.3-40 is designed for grading load shedding with energy deficit (partial failure of generation or transmission). The load-shedding program must be worked out which for example, disconnect **10 to 20D** of the consumers when the frequency falls to definite level. These consumers will be selected who are less sensitive to interruption to the supply and to stabilize the system again. A procedure of restoration generally enables the disconnected consumers to be reconnected reasonably quickly. Also, relays FCX 103 will apply:

- for splitting up a grid system by opening tie-lines to prevent complete system collapse. for isolating small systems having their own generation from the main system in the case of a fault in the latter (e.g. disconnection of an industrial system with its own generation).

- For the protection of generators and auxiliaries, where frequency supervision can avoid damage to turbines and auxiliary drives.

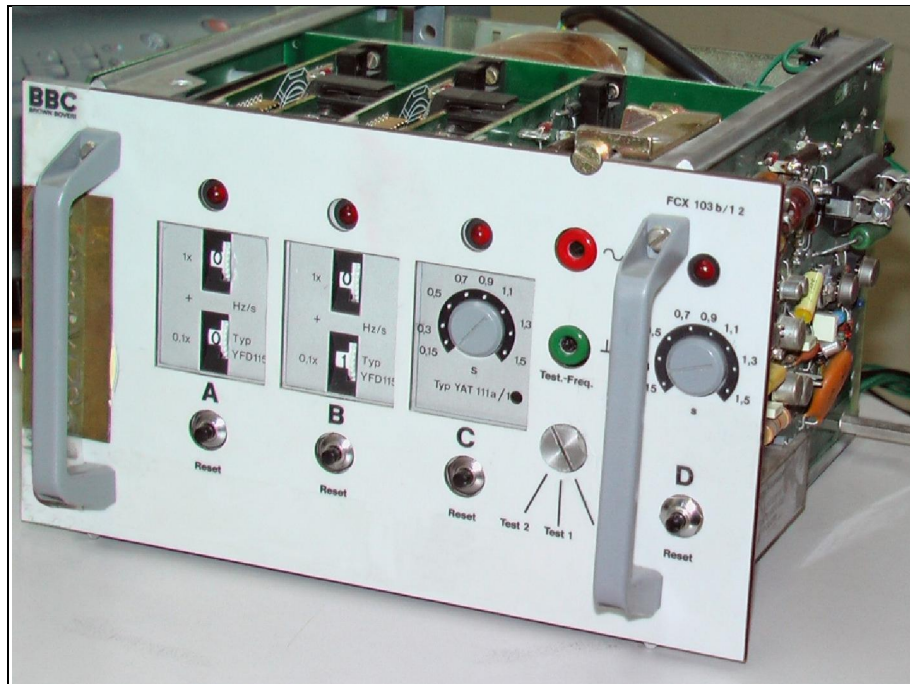


Fig 3.3-40 Frequency Relay Type FCX 103b

The basic unit contains one frequency measuring stage, but is designed to accept three additional stages, two of which can be combined under-frequency df/dt stages. The pick-up values of the various tripping stages are set by setting a code obtained from a table on a matrix plug-board located on the side of the basic unit. The tripping time [in the case of df/dt , the tripping frequency gradient] are set on the front of the relay, test switch and test sockets are situated. The operation is explained with the aid of the block diagram of Fig. 3.3-41 (basic unit with one frequency measuring stage). The high accuracy of the frequency measurement is the result of the digital measuring principle and the use of a quartz-controlled oscillator as frequency reference (Op). The number of cycles of the quartz oscillator, which take place during one period of the system frequency, are counted and the relay decides whether the system frequency is higher or lower than the value set on the relay. Tripping will occur if, during the time set on the potentiometer (et), the decision is consistently for over or under-frequency (depending on the function selected for the particular stage).

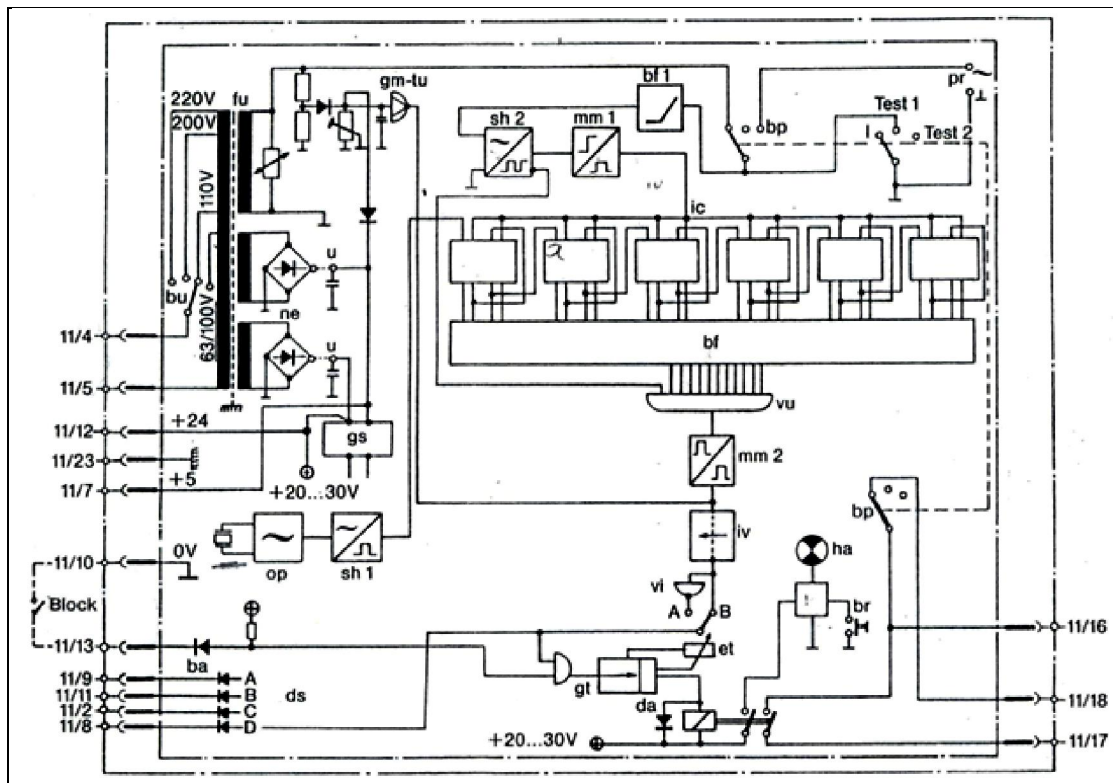


Fig 3.3-41 Block Diagram Basic Unit FCX 103b (1 Frequency Stage)

Bf _l	low-pass filter	ha	Tripping indicator
bf	Frequency selector plug-board	iv	Prolongation circuit
bp	Test switch	mm	Mono stable multi vibrator
br	Reset button	ne	Auxiliary supply
bu	Rated voltage selector	op	Quartz oscillator
ic	Counter	pr	Test signal input
da	Tripping contactor	sh	shaper
ds	Starting outputs	tu	Under voltage blocking
et	Time lag setting	vi	Inverter (amplifier)
fu	Voltage transformer	vu	Logic interlock (AND gate)
gm	Measuring unit (trigger)	u	Connections to choose auxiliary supply
gs	Stabilizing unit	ba	Blocking input
gt	Timer		

Legend of Fig 3.3-41

The quartz oscillator (Op) has a constant frequency of 100 KHz. Its reference oscillations are transformed into square waves by the shaper (sh1) and then continuously counted by the binary counter (ic). The input voltage is first passed through the low-pass filter (bfl) to remove any harmonics before also being transformed into a square-wave signal by the shaper (sh2).

This signal is applied to the monostable multivibrator (mml) which produces a 10 μ s impulse for each positive flank. The 10 μ s impulse is used to reset the counter (ic). At the instant the counter is reset, its count is proportional to the duration of the system frequency period. An inadmissible count is detected by means of the frequency selection plug board (bf) and the AND gate (VU). The pick-up frequency (period duration) is selected by connecting the corresponding direct and inverse outputs of the counter to the AND gate using the plug board.

For a pick-up frequency of for example 50 Hz, i.e. for a period of 20 ms, the direct and inverse outputs of the counter must be decoded in such a way that when the counter reaches 2000 (2000 oscillations of the 100-KHz quartz corresponds to 20 ms) a logic '1' appears at the output of the AND gate. As long as the frequency is higher than the set pick-up level (shorter period), the counter will always be reset before the set pick-up code is reached and the output of the AND gate will remain at '0'. A reduction in frequency, however, will generate one 10- s pulse per period at the output of the AND gate. (For the duration of one period of the quartz oscillator the pick-up code is fulfilled and all the inputs of the AND gate receive a digital '1'.)

The duration of these impulses is first increased by the monostable multivibrator (mm2) and then transformed into a continuous signal by the circuit (iv). This signal controls the timer (gt) either directly or via the inverter (vi). Operation with the inverter in circuit detects over frequency, whilst the direct connection between the prolongation circuit and the timer detects under frequency.

If the corresponding condition of under or over frequency is fulfilled for each period measured during the timer setting, the electromechanical output relay (da) will be

energized. Once contact of this output relay is connected via the test switch (bp) -to external terminals for controlling a tripping relay, the second contact excites the visual signal (ha) [a light-emitting diode that can be reset by the push-button (br)]. Because the measurement of the frequency is digital for which only the zeros of the system voltage and not its amplitude are of consequence, the relay is independent of voltage fluctuations within a wide range. However, should the system voltage sink below a level into a region in which accurate measurement can no longer be expected, an under-voltage supervision circuit (gm-tu) picks up and blocks all outputs. The actual level is set internally in the relay and is dependent on the method of auxiliary supply. (The relay can also be blocked by applying a '0' signal available at terminal 11/10 terminal 11/13.)

Depending on the internal circuitry, the auxiliary supply for the electronic circuits is either obtained from the input voltage signal or from an external source of 24 V DC. In the former case the input transformer (fu) has two windings and the rectifier bridges (ne) are provided. The station battery is then only required for energizing the tripping relay and the breaker tripping coil.

When the auxiliary is obtained internally, the consumption of the relay (demands on the main CT) depends on the number of measuring stages, so that the under-voltage blocking relay may not be set to less than 0.6 UN.

A much lower consumption and wider voltage range (down to a minimum of 0.2 UN) can be obtained by using an external source of 24 V dc. For battery voltages between 48 and 250 V a relay casing type YUR 102 (with built-in power supply is available. In this case the tripping relays are supplied at the internal voltage of 24 V dc.

SETTING THE PICK-UP FREQUENCY:

An individual pickup frequency setting is provided for each stage. Setting is carried out on the plug-board (matrix) on the left-hand side of the basic unit. The arrangement of the plugs is given in a table of codes (see table 1 and 2 in the next page). This setting is also required in the case of the frequency gradient units for the under frequency starting level.

MEASURING STAGES:

The relay is equipped with or up to four measuring stages, (**A**, **B**, **C**, and **D**). Stage **D** is a part from the basic unit while the other stages are supplementary plug-in units.

OPERATING TIME LAG (See the following Table):

The operating time-lag of each stage can be set individually. The YAT unit can be supplied with timer setting ranges of 0.1S to 1.5 S or 0.5 to 5 S. The timer setting on the YAT units is continuously variable potentiometer located in the front. The time lag of the frequency gradient units YFD 115 is set internally and selected from the fixed values 33, 66, 99, or 132 ms.

UNDER AND OVER FREQUENCY MEASUREMENTS

Each frequency stage can be adapted as desired for under or over frequency measurement. The selection is by means of soldered link in the respective unit, and by adding or removing a diode.

SUPERVISING THE CONDITION OF THE RELAY AND TESTING

An alarm connected to a normally closed contact of the tripping relay of this unit will be actuated in the event of a defect in the input, oscillator or counter circuit of the relay or if the auxiliary supply of the relay should be interrupted. If a relay with supervision also has over frequency stages, their outputs are interlocked by normally-opened contacts of the supervision stage. In position "Test I" of the test switch (bp) it is possible to check the integrity of the output stages. The function of the test switch positions are as follows:

- Position "1", the relay is in service and in the event of inadmissible frequency fluctuations of sufficient duration tripping will take place.
- Position "Test 1", the tripping circuits are interrupted and the over frequency stages must pick-up after their

- Position of "Test 2", the tripping circuit are interrupted and the input of the measuring unit is connected to the test socket (pr) in the front of the relay. A signal generator can be plugged into these sockets to check the pickup values of the various stages (under as well as over frequency - signal voltage 3-20 Vrms).

Switching to this position without a signal connected to the sockets (pr) will cause a supervision stage to pick-up instantaneously and over frequency stages after their set time lag.

	10		9		8		7		6		5		4		3		2		1	
	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1
A	○	●	○	●	○	●	○	●	●	○	○	●	●	○	○	●	○	●	○	●
B	○	●	○	●	○	●	○	●	○	●	●	○	○	●	●	○	○	●	○	●
C	●	○	●	○	●	○	●	○	●	○	●	○	●	○	○	●	●	○	●	○
D	●	○	●	○	●	○	●	○	●	○	○	●	○	●	○	●	○	●	○	●

Table 1 – Example of a frequency setting:
 Step A starting frequency 49.8 Hz
 Step B starting frequency 49.3 Hz
 Step C starting frequency 48.7 Hz
 Step D starting frequency 48.1 Hz

Hz	Plug No.	Hz	Hz	Hz	Hz	Hz
	10 9 8 7 6 5 4 3 2 1	10 9 8 7 6 5 4 3 2 1	10 9 8 7 6 5 4 3 2 1	10 9 8 7 6 5 4 3 2 1	10 9 8 7 6 5 4 3 2 1	10 9 8 7 6 5 4 3 2 1
39.1	0 1 1 1 1 1 1 1 0 1	44.0 0 0 1 1 1 0 0 0 0 0	49.0 1 1 1 1 1 1 1 0 0 0	54.0 1 1 0 0 1 1 1 0 1 1	59.0 1 0 1 0 0 1 1 1 1 0	64.0 1 0 0 0 0 1 1 0 1 0
39.2	0 1 1 1 1 1 0 1 1 0	44.1 0 0 1 1 0 1 1 0 1 1	49.1 1 1 1 1 1 1 0 1 0 0	54.1 1 1 0 0 1 1 0 1 1 1	59.1 1 0 1 0 0 1 1 0 1 1	64.1 1 0 0 0 0 1 0 1 1 1
39.3	0 1 1 1 1 1 0 0 0 0	44.2 0 0 1 1 0 1 0 1 0 1	49.2 1 1 1 1 1 1 0 0 0 0	54.2 1 1 0 0 1 1 0 1 0 0	59.2 1 0 1 0 0 1 1 0 0 0	64.2 1 0 0 0 0 1 0 1 0 1
39.4	0 1 1 1 1 0 1 0 0 1	44.3 0 0 1 1 0 1 0 0 0 0	49.3 1 1 1 1 1 1 0 0 1 1	54.3 1 1 0 0 1 1 0 0 0 1	59.3 1 0 1 0 0 1 1 0 1 0	64.3 1 0 0 0 0 1 0 0 1 0
39.5	0 1 1 1 1 0 0 0 1 1	44.4 0 0 1 1 0 0 1 0 1 1	49.4 1 1 1 1 1 1 0 0 1 1	54.4 1 1 0 0 1 0 1 1 0 1	59.4 1 0 1 0 0 1 0 0 1 1	64.4 1 0 0 0 0 1 0 0 0 0
39.6	0 1 1 1 0 1 1 1 0 0	44.5 0 0 1 1 0 0 0 1 1 0	49.5 1 1 1 1 1 0 0 0 1 1	54.5 1 1 0 0 1 0 1 0 1 0	59.5 1 0 1 0 0 1 0 0 0 0	64.5 1 0 0 0 0 1 1 0 1 1
39.7	0 1 1 1 0 1 0 1 1 0	44.6 0 0 1 1 0 0 0 0 0 1	49.6 1 1 1 1 0 1 1 1 1 1	54.6 1 1 0 0 1 0 0 1 1 1	59.6 1 0 1 0 0 0 1 1 0 1	64.6 1 0 0 0 0 1 0 1 1 1
39.8	0 1 1 1 0 1 0 0 0 0	44.7 0 0 1 0 1 1 1 1 0 0	49.7 1 1 1 1 0 1 1 0 1 1	54.7 1 1 0 0 1 0 0 0 1 1	59.7 1 0 1 0 0 0 1 0 1 0	64.7 1 0 0 0 0 1 0 0 1 0
39.9	0 1 1 1 0 0 1 0 0 1	44.8 0 0 1 0 1 1 0 1 1 1	49.8 1 1 1 1 0 1 0 1 1 1	54.8 1 1 0 0 1 0 0 0 0 0	59.8 1 0 1 0 0 0 0 1 1 1	64.8 1 0 0 0 0 0 0 1 1 0
		44.9 0 0 1 0 1 1 0 0 1 0	49.9 1 1 1 1 0 1 0 0 1 1	54.9 1 1 0 0 0 1 1 1 0 1	59.9 1 0 1 0 0 0 0 1 0 1	64.9 1 0 0 0 0 0 0 1 0 0
40.0	0 1 1 1 0 0 0 0 0 1	45.0 0 0 1 0 1 0 1 1 0 1	50.0 1 1 1 1 0 0 1 1 1 1	55.0 1 1 0 0 0 1 1 0 0 1	60.0 1 0 1 0 0 0 0 0 1 0	65.0 1 0 0 0 0 0 0 0 1 0
40.1	0 1 1 1 0 1 1 1 0 1	45.1 0 0 1 0 1 0 1 0 0 0	50.1 1 1 1 1 0 0 0 1 0 1	55.1 1 1 0 0 0 1 0 1 1 0	60.1 1 0 0 1 1 1 1 1 1 1	
40.2	0 1 1 0 1 1 0 1 1 1	45.2 0 0 1 0 1 0 0 0 1 1	50.2 1 1 1 1 0 0 0 0 1 1	55.2 1 1 0 0 0 1 0 0 1 1	60.2 1 0 0 1 1 1 1 1 0 0	
40.3	0 1 1 0 1 1 0 0 0 0	45.3 0 0 1 0 1 0 0 1 1 1 1	50.3 1 1 1 1 0 0 0 0 0 1	55.3 1 1 0 0 0 0 1 1 1 1	60.3 1 0 0 1 1 1 1 0 0 1	
40.4	0 1 1 0 1 0 1 0 1 0	45.4 0 0 1 0 1 0 0 1 0 1 0	50.4 1 1 1 0 1 1 1 1 1 1	55.4 1 1 0 0 0 0 1 1 0 0	60.4 1 0 0 1 1 1 0 1 1 1	
40.5	0 1 1 0 1 0 0 1 0 0	45.5 0 0 1 0 1 0 0 1 0 1 0	50.5 1 1 1 0 1 1 1 0 1 1	55.5 1 1 0 0 0 0 1 0 0 1	60.5 1 0 0 1 1 1 0 1 0 0	
40.6	0 1 1 0 0 1 1 1 1 0	45.6 0 0 1 0 1 0 0 0 0 0	50.6 1 1 1 0 1 1 0 1 1 1	55.6 1 1 0 0 0 0 0 1 1 0	60.6 1 0 0 1 1 1 0 0 0 1	
40.7	0 1 1 0 0 1 1 0 0 0	45.7 0 0 1 0 1 0 0 0 1 0 1	50.7 1 1 1 0 1 1 0 0 1 1	55.7 1 1 0 0 0 0 0 0 1 0	60.7 1 0 0 1 1 0 1 1 1 1	
40.8	0 1 1 0 0 1 0 0 1 0	45.8 0 0 1 0 1 0 0 0 1 1 0	50.8 1 1 1 0 1 1 0 0 0 0	55.8 1 0 1 1 1 1 1 1 1 1	60.8 1 0 0 1 1 0 1 1 0 0	
40.9	0 1 1 0 0 0 1 1 0 0	45.9 0 0 1 0 1 0 0 0 0 1 0	50.9 1 1 1 0 1 0 1 1 0 0	55.9 1 0 1 1 1 1 1 1 0 0	60.9 1 0 0 1 1 0 1 0 0 1	
41.0	0 1 1 0 0 0 0 1 1 0	46.0 0 0 0 1 1 1 1 1 0 1	51.0 1 1 1 0 1 0 1 0 0 0	56.0 1 0 1 1 1 1 1 0 0 1	61.0 1 0 0 1 1 0 0 1 1 0	61.1 1 0 0 1 1 0 0 1 0 0
41.1	0 1 1 0 0 0 0 0 0 0	46.1 0 0 0 1 1 1 1 0 0 0	51.1 1 1 1 0 1 0 0 1 0 0	56.1 1 0 1 1 1 1 0 1 1 0	61.1 1 0 0 1 1 0 0 1 0 0	
41.2	0 1 0 1 1 1 1 0 1 0	46.2 0 0 0 1 1 1 0 1 0 0	51.2 1 1 1 0 1 0 0 0 0 0	56.2 1 0 1 1 1 1 0 0 1 0	61.2 1 0 0 1 1 0 0 0 1 1	
41.3	0 1 0 1 1 1 0 1 0 0	46.3 0 0 0 1 1 0 1 1 1 1	51.3 1 1 1 0 0 1 1 1 0 0	56.3 1 0 1 1 1 0 1 1 1 1	61.3 1 0 0 1 1 0 1 1 1 0	
41.4	0 1 0 1 1 0 1 1 1 0	46.4 0 0 0 1 1 0 1 0 1 0	51.4 1 1 1 0 0 1 1 0 0 1	56.4 1 0 1 1 1 0 1 1 0 0	61.4 1 0 0 1 1 0 1 1 0 0	
41.5	0 1 0 1 1 0 1 0 0 1	46.5 0 0 0 1 1 0 0 1 1 0	51.5 1 1 1 0 0 1 0 1 0 1	56.5 1 0 1 1 1 0 1 0 0 1	61.5 1 0 0 1 1 0 1 1 0 0	
41.6	0 1 0 1 1 0 0 0 1 1	46.6 0 0 0 1 1 0 0 0 0 1	51.6 1 1 1 0 0 1 0 0 0 1	56.6 1 0 1 1 1 0 0 1 1 0	61.6 1 0 0 1 1 0 1 0 1 0	
41.7	0 1 0 1 0 1 1 1 0 1	46.7 0 0 0 1 0 1 1 1 0 0	51.7 1 1 1 0 0 0 1 1 0 1	56.7 1 0 1 1 1 0 0 0 1 1	61.7 1 0 0 1 1 0 1 0 1 0	
41.8	0 1 0 1 0 1 0 1 1 1	46.8 0 0 0 1 0 1 1 0 0 0	51.8 1 1 1 0 0 0 0 1 0 1 0	56.8 1 0 1 1 0 0 0 0 0 0	61.8 1 0 0 1 1 0 1 0 0 1	
41.9	0 1 0 1 0 1 0 0 1 0	46.9 0 0 0 1 0 1 0 0 1 1	51.9 1 1 1 0 0 0 0 0 1 1 0	56.9 1 0 1 1 0 1 1 1 0 1	61.9 1 0 0 1 1 0 0 1 1 1	
42.0	0 1 0 1 0 0 1 1 0 0	47.0 0 0 0 1 0 0 1 1 1 1	52.0 1 1 1 0 0 0 0 0 1 0	57.0 1 0 1 1 0 1 1 0 0 1	62.0 1 0 0 1 0 0 1 1 0 0	62.1 1 0 0 1 0 0 1 0 0 1
42.1	0 1 0 1 0 0 0 1 1 0	47.1 0 0 0 1 0 0 1 0 1 0	52.1 1 1 0 1 1 1 1 1 1 0	57.1 1 0 1 1 0 1 0 1 1 0	62.1 1 0 0 1 0 0 1 0 0 1	
42.2	0 1 0 1 0 0 0 0 0 1	47.2 0 0 0 1 0 0 0 1 1 0	52.2 1 1 0 1 1 1 1 0 1 1	57.2 1 0 1 1 0 1 0 0 1 1	62.2 1 0 0 1 0 0 0 1 1 1	
42.3	0 1 0 0 1 1 1 0 1 1	47.3 0 0 0 1 0 0 0 0 0 1	52.3 1 1 0 1 1 1 0 1 1 1	57.3 1 0 1 1 0 1 0 0 0 0	62.3 1 0 0 1 0 0 0 0 1 0	
42.4	0 1 0 0 1 1 0 1 1 0	47.4 0 0 0 0 1 1 1 1 0 1	52.4 1 1 0 1 1 1 0 0 1 1	57.4 1 0 1 1 0 0 1 1 0 1	62.4 1 0 0 1 0 0 0 0 1 0	
42.5	0 1 0 0 1 1 0 0 0 0	47.5 0 0 0 0 1 1 1 0 0 0	52.5 1 1 0 1 1 1 0 0 0 0	57.5 1 0 1 1 0 0 1 0 1 0	62.5 1 0 0 0 1 1 1 1 1 1	
42.6	0 1 0 0 1 0 1 0 1 0	47.6 0 0 0 0 1 1 0 1 0 0	52.6 1 1 0 1 1 0 1 1 0 0	57.6 1 0 1 1 0 0 0 1 1 1	62.6 1 0 0 0 1 1 1 0 1 0	
42.7	0 1 0 0 1 0 0 1 0 1	47.7 0 0 0 0 1 0 1 1 1 1	52.7 1 1 0 1 1 0 1 0 0 1	57.7 1 0 1 1 0 0 0 1 0 0	62.7 1 0 0 0 1 1 1 0 1 0	
42.8	0 1 0 0 0 1 1 1 1 1	47.8 0 0 0 0 1 0 1 0 1 1	52.8 1 1 0 1 1 0 0 1 0 1	57.8 1 0 1 1 0 0 0 0 0 1	62.8 1 0 0 0 1 1 0 1 1 1	
42.9	0 1 0 0 0 1 1 0 1 0	47.9 0 0 0 0 1 0 0 1 1 1	52.9 1 1 0 1 1 0 0 0 0 1	57.9 1 0 1 1 0 1 1 1 1 0	62.9 1 0 0 0 1 1 0 1 1 0	
43.0	0 1 0 0 0 1 0 1 0 1	48.0 0 0 0 0 1 0 0 0 1 0	53.0 1 1 0 1 0 1 1 1 1 0	58.0 1 0 1 0 1 1 1 0 1 1	63.0 1 0 0 0 1 1 0 0 1 0	63.1 1 0 0 0 1 1 0 0 0 0
43.1	0 1 0 0 0 0 1 1 1 1	48.1 0 0 0 0 0 1 1 1 1 0	53.1 1 1 0 1 0 1 1 0 1 0	58.1 1 0 1 0 1 1 1 0 0 0	63.1 1 0 0 0 1 1 0 0 0 0	
43.2	0 1 0 0 0 0 0 1 0 1	48.2 0 0 0 0 0 1 1 0 1 0	53.2 1 1 0 1 0 1 0 1 1 1	58.2 1 0 1 0 1 1 0 1 0 1	63.2 1 0 0 0 1 0 1 0 1 0	
43.3	0 1 0 0 0 0 0 0 1 0	48.3 0 0 0 0 0 1 0 1 0 1	53.3 1 1 0 1 0 1 0 0 1 1	58.3 1 0 1 0 1 1 0 0 1 0	63.3 1 0 0 0 1 0 1 0 1 1	
43.4	0 0 1 1 1 1 1 1 1 1	48.4 0 0 0 0 0 1 0 0 0 1	53.4 1 1 0 1 0 1 0 0 0 0	58.4 1 0 1 0 1 0 1 1 1 1	63.4 1 0 0 0 1 0 1 0 0 0	
43.5	0 0 1 1 1 1 1 0 1 0	48.5 0 0 0 0 0 1 0 0 1 1	53.5 1 1 0 1 0 0 1 1 0 0	58.5 1 0 1 0 1 0 1 1 0 0	63.5 1 0 0 0 1 0 0 0 1 1	
43.6	0 0 1 1 1 1 0 1 0 1	48.6 0 0 0 0 0 1 0 0 1 1	53.6 1 1 0 1 0 0 1 0 0 1	58.6 1 0 1 0 1 0 1 0 1 0	63.6 1 0 0 0 1 0 0 0 1 1	
43.7	0 0 1 1 1 0 1 1 1 1	48.7 0 0 0 0 0 0 1 0 1 0	53.7 1 1 0 1 0 0 0 1 0 1	58.7 1 0 1 0 1 0 0 1 1 1	63.7 1 0 0 0 1 0 0 0 0 1	
43.8	0 0 1 1 1 0 1 0 1 0	48.8 0 0 0 0 0 0 0 0 0 0	53.8 1 1 0 1 0 0 0 0 1 0	58.8 1 0 1 0 1 0 0 0 1 0	63.8 1 0 0 0 1 1 1 1 1 0	
43.9	0 0 1 1 1 0 0 1 0 1	48.9 1 1 1 1 1 1 1 1 1 0	53.9 1 1 0 0 1 1 1 1 1 0	58.9 1 0 1 0 1 0 0 0 0 1	63.9 1 0 0 0 1 1 1 0 0 0	

Table 3.3-1 setting table for frequency relay type FCX 103

FREQUENCY GRADIENT (DF/DT) UNIT TYPE YFD115:

Position A and B of the basic relay type FCX 103b are designed to accept df/dt units type YFD 115 instead of the normal frequency measuring stages type YAT.

They are used for load shedding in graded load - shedding applications. With their help it is possible to trip the second or even the third stage of load shedding upon reaching the level of the first stage provided the energy deficits large enough (large df/dt).

Three criteria must thus be fulfilled before df/dt tripping can take place:

1. The frequency must be below the starting frequency (set in the basic unit).
2. The df/dt must be greater than the setting.
3. The df/dt must remain greater than the setting for the set time.

The unit measures with great accuracy every period of system frequency and compares it with previous one, checking whether it is longer and if so by how much. The frequency gradient at which the relay picks up is set in steps in the front of the unit. In addition tripping cannot take place unless the starting frequency set in the basic unit and both these criteria have persisted for the set time - lag. The measurements makes use of four signals, which are already available in the basic unit:

1. The 100 KHz reference signal.
2. The pulse of 10 μ sec. generates at each zero of the input voltage (ME).
3. & starting signal from the frequency measurement (10 m sec. pulse).
4. The blocking facility of the under voltage supervision (BL).

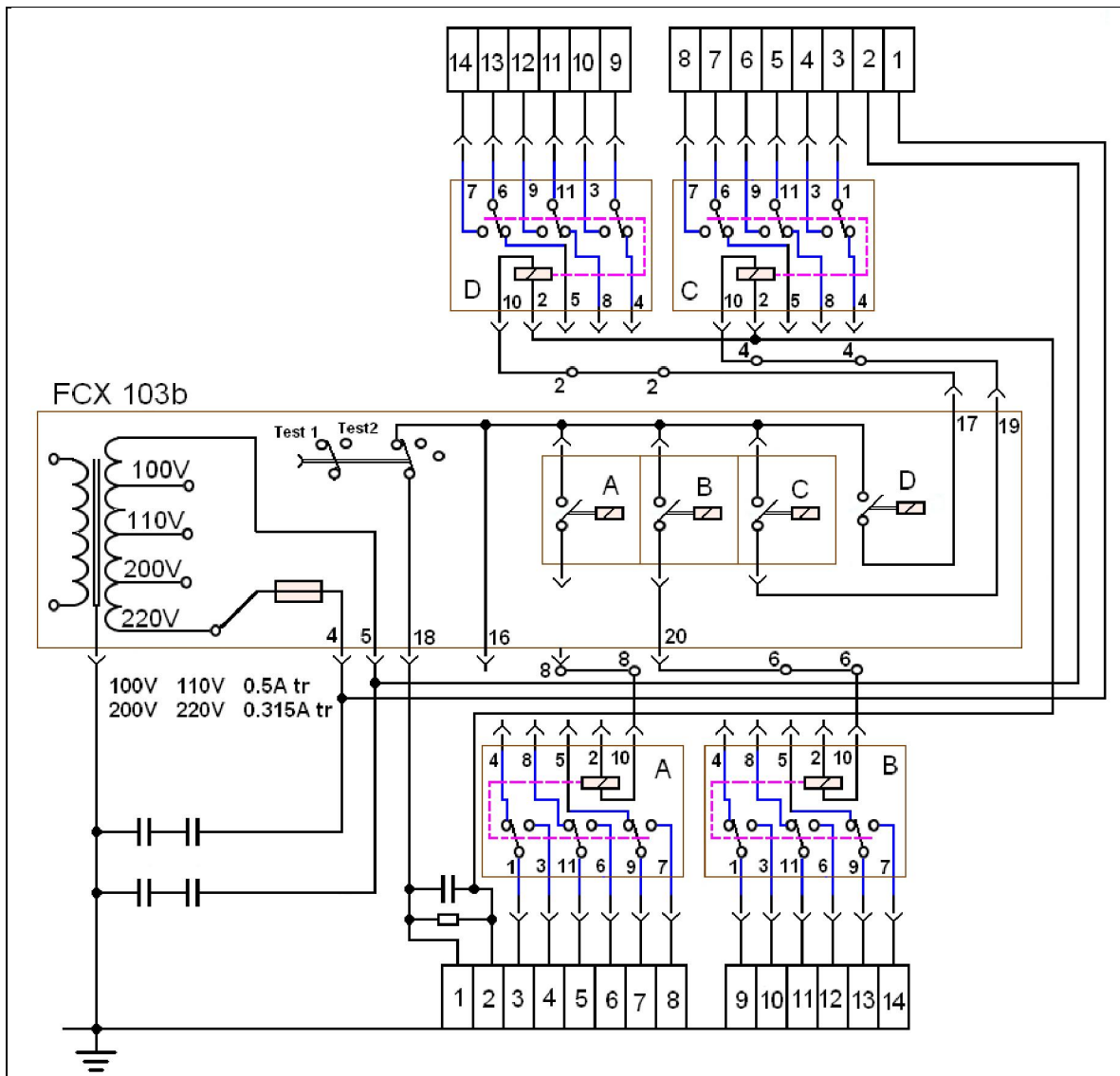


Fig 3.3-42 Wiring Diagram Relay Casing

SUMMARY

- When the loads of power systems suddenly exceed the available generating capacity, the generators begin to slow down as they attempt to carry the excessive load.
- As the speed slows the frequency decreases below normal and the system voltage decreases. Further, the drop in frequency may endanger generation itself and may leads to loss of power.
- The thermal generating plant is quite sensitive to frequency reduction.

- The only one way to save a system from complete collapse as a result of under-frequency is to shed the load in order to balance load and generation.
- Load shedding is performed by frequency relays. Frequency relays for this application must be independent of the voltage (as the voltage sinks at the sometime) and be very accurate.
- Most of the reference papers state that 60 Hz system, at frequency of 56 to 58 Hz is low enough to endanger power plants equipment.
- Load shedding is accomplished by using several groups of frequency relays, each controlling its own block of load and each set to a successively lower frequency.
- Frequency relays either under or over frequency as well as rate of change of frequency.
- When the frequency falls to definite level, the load-shedding program must be worked out to disconnect number of consumers. These consumers will be selected who are less sensitive to interruption to the supply and to stabilize the system again.
- Electronic frequency relay is designed for grading load shedding with energy deficit (partial failure of generation or transmission). A procedure of restoration generally enables the disconnected consumers to be reconnected reasonably quickly.
- Also, Electronic frequency relays will apply:
 - i. For splitting up a grid system by opening tie-lines to prevent complete system collapse.
 - ii. For isolating small systems having their own generation from the main system in the case of a fault in the latter (e.g. disconnection of an industrial system with its own generation).
 - iii. for the protection of generators and auxiliaries, where frequency supervision can avoid damage to turbines and auxiliary drives

REVIEW EXERCISE

1. When the loads of power systems suddenly exceeds the available generating capacity, the generators
 - a) begin to slow down its speed
 - b) begin to accelerate its speed
 - c) breaker will trip instantaneously
 - d) speed will not change
2. The only one way to save a system from complete collapse as a result of under-frequency is _____
 - to increase the load
 - to shed the load
 - increase the excitation
 - decrease the excitation
3. Load shedding is performed by _____
 - Over current relays
 - distance relays
 - frequency relays
 - under voltage relays
4. 60 Hz system, at frequency _____ of is low enough to endanger power plants equipment
 - 58-59 Hz
 - 57-59 Hz
 - 56-58 Hz
 - 46-48 Hz

TASK 3.3-3

TESTING OVER/UNDER STATIC FREQUENCY RELAY

OBJECTIVES

Upon completion of this task, the trainee will be able to perform all type of the required tests on the Static frequency relay .with a high accuracy and with a tolerance permitted in the instructional manual.

TOOLS, MATERIALS & REQUIREMENTS

- BBC static frequency relay type FCX 103 b
- FREJA 306 Test set
- Relay technician tool kit.

PROCEDURE

1. Testing the pickup test for under and over frequency units

- Connect the terminals 4 &5 of the relay to the terminals NU & L1U (9)on the FREJA test set shown in the figure below:

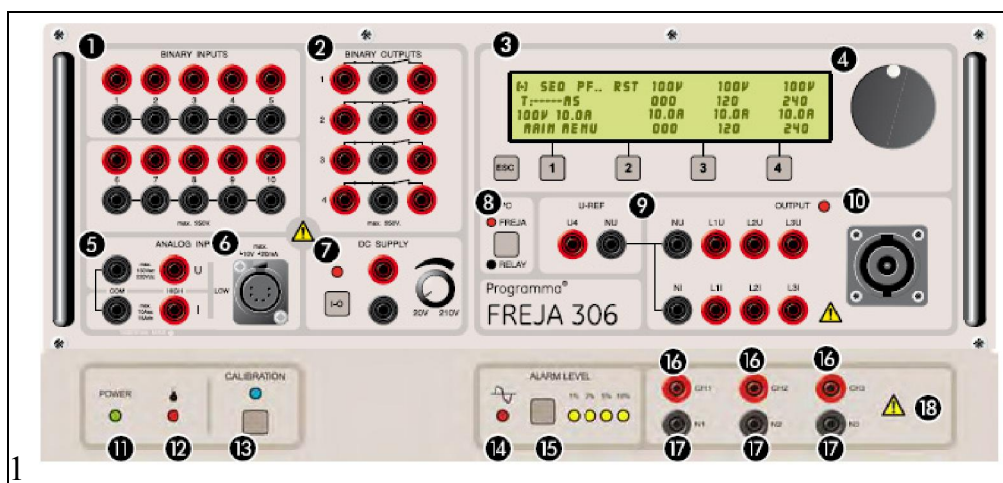


Fig. 3-1

- Connect the trip contact terminals 17 & 18 of stage D (or 18&19 for stage C or 18&20 for stage B or 18&21 for stage A) according to the stage under test to the binary input 1 (1) on the FREJA test set
- Switch on the test unit and wait to warm up
- Press **Esc**
- Select general then page 1/7 appears.

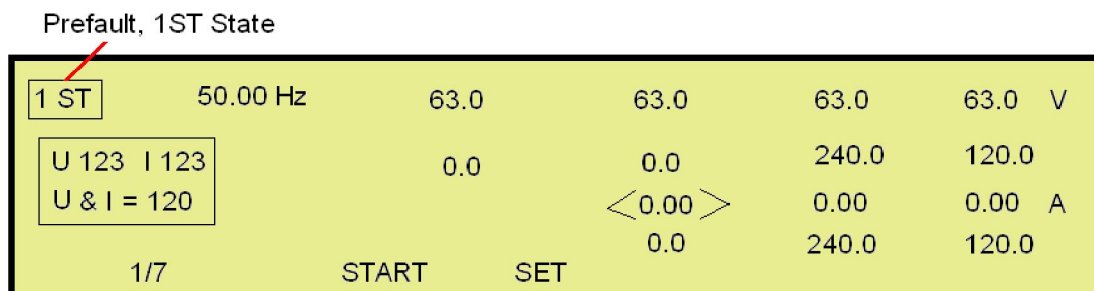


Fig. 3-2

- Select the voltage setting of the first phase by turning the dial (4) and press the dial and Set phase voltage to 63V then press the dial
- Select the frequency setting and press the dial the set to 60 Hz. This is the pre-fault, value (1st state).
- Go to page 2/7 by pressing button 1 on (3)

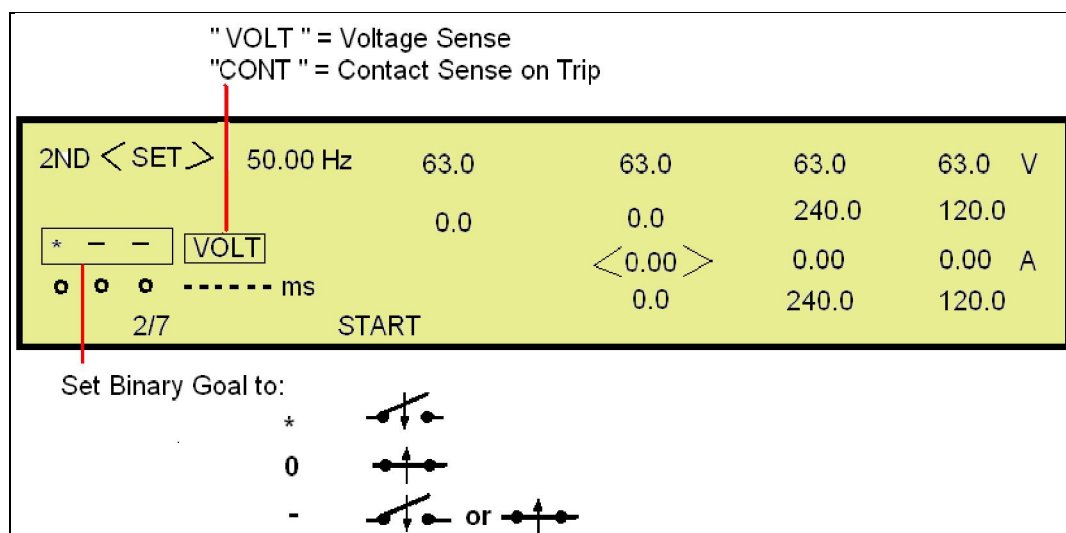


Fig. 3-3

- Set the binary goal (binary input 1 to * (STAR) for NO relay trip contact

Note

Binary goal is an AND function, this means if you set *** on all three inputs, you must have signals on all three inputs before the goal has reached.

- Set the contact as dry one ("CONT")
- Set the fault (2nd set) to a value below the under frequency stage setting or above the over frequency stage setting
- Set the voltage for the 1st phase on 63 V
- Go to page 4/7 by pressing button (1) on (3) twice

RAMP	du/dt	: < 5.0 >	$dU\phi/dt$:	0.0
* - -	dI/dt	: 0.0	$dI\phi/dt$:	0.0
O O O			df/dt	:	0.000
4/7	Start		Report		

Fig. 3-4

This is the Ramp page. You make a ramp from the setting values of page 2 with the speed we define here (the values are per second).

The “Ramp” menu is used to search for a frequency border

- Set the ramp df/dt to a suitable value for accurate measurement but let it be more than the setting of the df/dt stages to be away from its operating rate of change
- Press “Start”, button "2" on page 4/7 to measure the pickup value
- Press “Start”, button "2" on page 4/7 to measure the trip time

2- Testing the rate of change (df/dt) units

The same procedure as previous steps but change setting of df/dt in page 4/7 will be according to the setting of the df/dt units

Do this test several times (say for 3 values) until operation

STATIC DIFFERENTIAL RELAY

INTRODUCTION

By Kirchhoff's law the vector sum of all the currents entering a circuit should be zero unless an additional current path is added (i.e. a fault) whose current is not included in the vector sum. Consequently, if the secondaries of the CT in all connections to the protected circuit are paralleled with each other and a relay, no current should flow in the relay unless there is a fault in the protected circuit, which provides an additional shunt path (Fig 3.3-43).

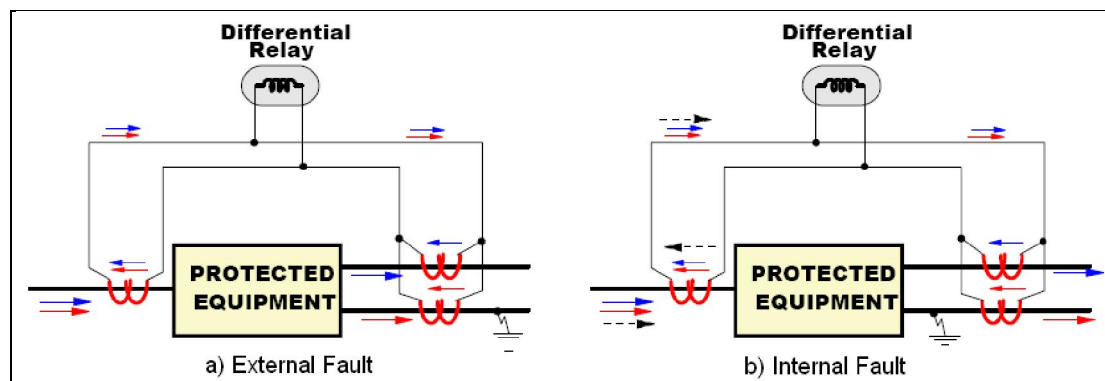


Fig 3.3-43. Basic Principle of Longitudinal Differential Protection

MERITS OF STATIC DIFFERENTIAL PROTECTION

- Three phase relay set with small dimensions.
- Absolute stability for heavy through faults, hence ideally preferred for large transformers, generators.
- High sensitivity for internal faults.
- Extremely short tripping times regardless of magnitude of auxiliary voltage. (e.g., 20-50 ms).
- Accurate and absolutely stable tripping characteristic even for asymmetrical faults as each phase can have its own relay.
- Inrush-proof, even during high starting currents, inrush currents.

- Low consumption (VA burden on instrument transformers).

APPLICATIONS

- Protection of generators.
- Protection of generator-transformer units.
- Protection of two winding transformers.
- Protection of three winding transformers for:
 - a) Two and three phase faults.
 - b) Earth faults in transformers with solidly grounded neutral or low resistance grounded neutral.
 - c) Earth faults in generators with solidly grounded neutral or low resistance grounded neutral.
 - d) Inter-turn faults.

TYPES OF DIFFERENTIAL RELAYS

The following types are normally used:

- a) Unbiased relay (Merz-Price type)
- b) Percentage bias differential relay
- c) High speed differential relay with harmonic restraint feature
- d) High impedance type differential relay

a) UNBIASED DIFFERENTIAL RELAY

This is the simplest type in which the vector difference current gives rise to relay operation. This scheme lacks stability as under very sensitive settings the relay is liable to operate under unbalance currents caused by differences in CT. characteristics during steady state or transient conditions. High current settings are therefore to be adopted. Such schemes need stabilizing resistors in the relay circuit and balancing resistors in the CT. loop circuits.

The stabilizing resistor is used to stabilize the relay under through fault condition. It can be shown that if one CT. is completely saturated the relay current is given by

where:
$$I_{Relay} = I_{Through Fault} \left(\frac{R_B}{R_Y} \right)$$

R_B is the resistance of the saturated CT and its leads to the relay and

R_Y is the stabilizing resistor. By increasing the value of R_Y suitably, the relay current can be decreased.

The balancing resistor are needed in the CT loops so that the relay is connected at a point such that the voltage drops on either side of it to each CT are equal, i.e. the relay point is the electrical center of gravity between the two CT's.

Unbiased relays are used mainly for generators (by some manufacturers) and for transformers less than 2 MVA.

b) PERCENTAGE BIAS DIFFERENTIAL RELAY (Fig 3.3-44)

This type of relay has bias windings to provide stability on external faults. As already discussed the percent bias provided varies from 5 to 50 percent depending on application and requirements. Operating current settings provided in these relays normally vary from 10 to 100 percent. In such relays an inherent time delay is sometimes provided to overcome unwanted operation on magnetizing inrush currents. Such relays can be used for transformer ratings up to **10 to 15 MVA**.

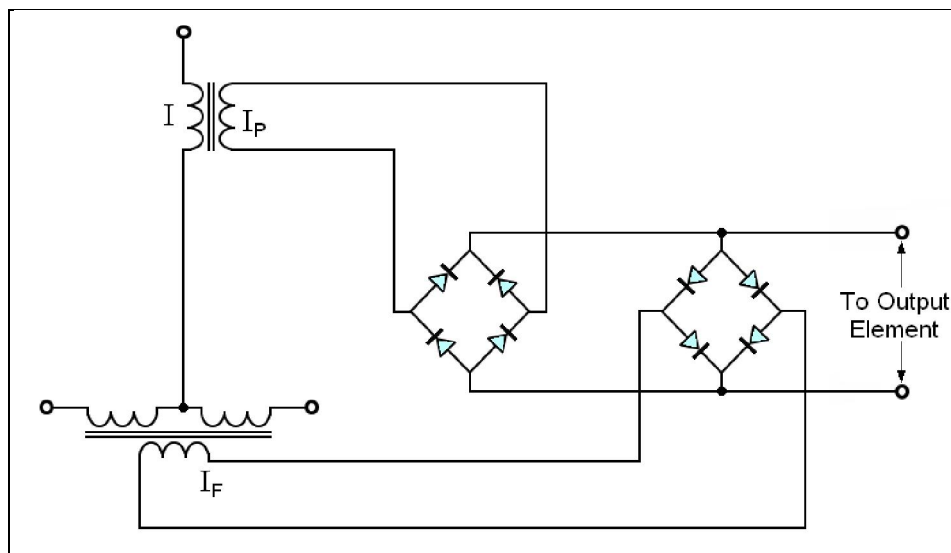


Fig 3.3-44 Percentage Differential Relay

STATIC RELAYS SCHEMES

The rectifier bridge amplitude comparator, as already mentioned, appears to be the most widely used static element for this purpose. Static schemes are also capable of being combined into polyphase schemes unlike e.m. types. The basic scheme based on single-phase operation is shown in Fig 3.3-39. Scheme (a) shows the block diagram, while scheme (b) (i) shows the basic amplitude comparator application for single-phase schemes. Scheme (b) (ii) shows the comparator application used by one of the manufacturers specially for polyphase application, shown in Fig 3.3-45.

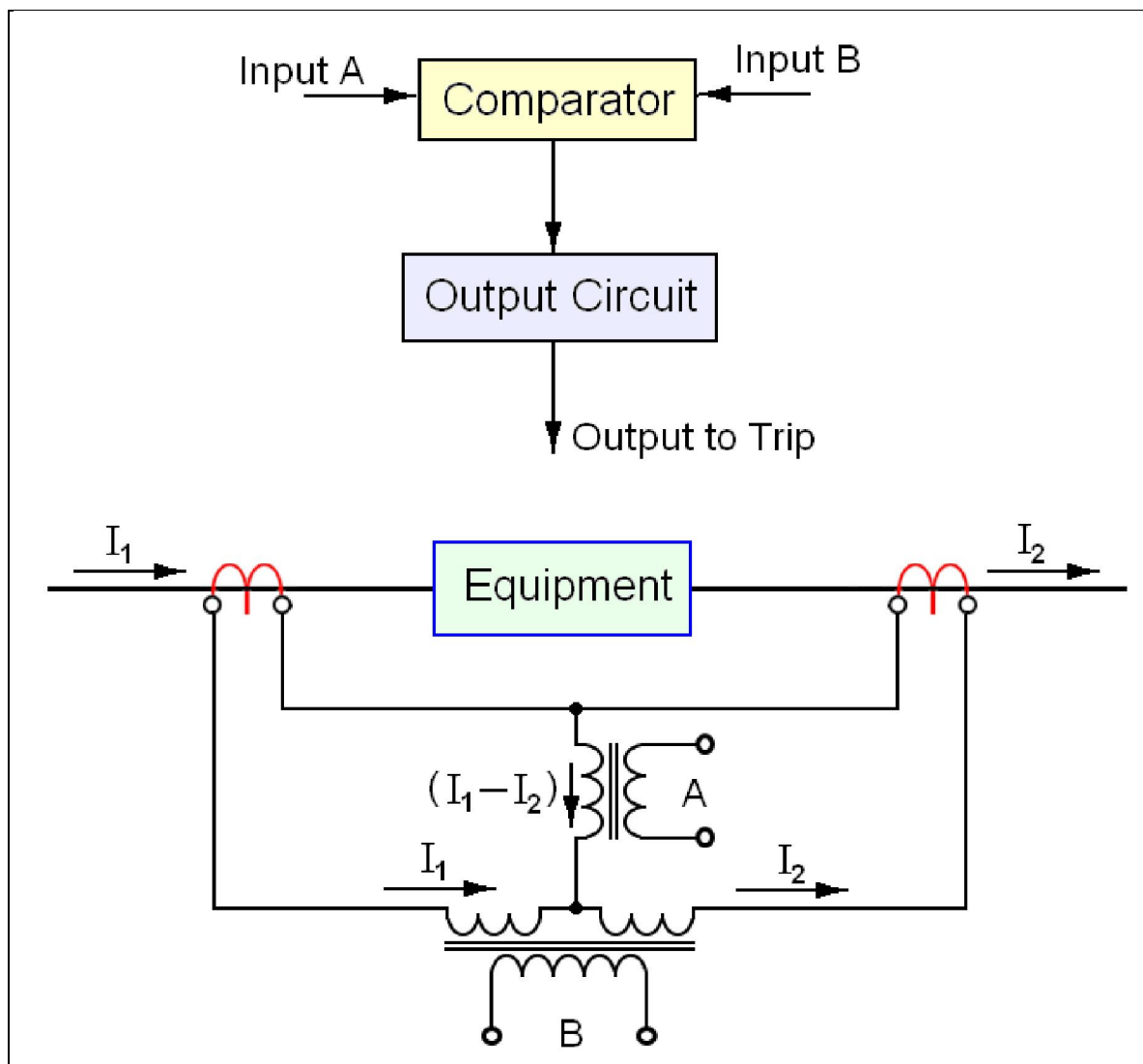


Fig 3.3-45 Basic Scheme For Rectifier Bridge Amplitude Comparator (A)

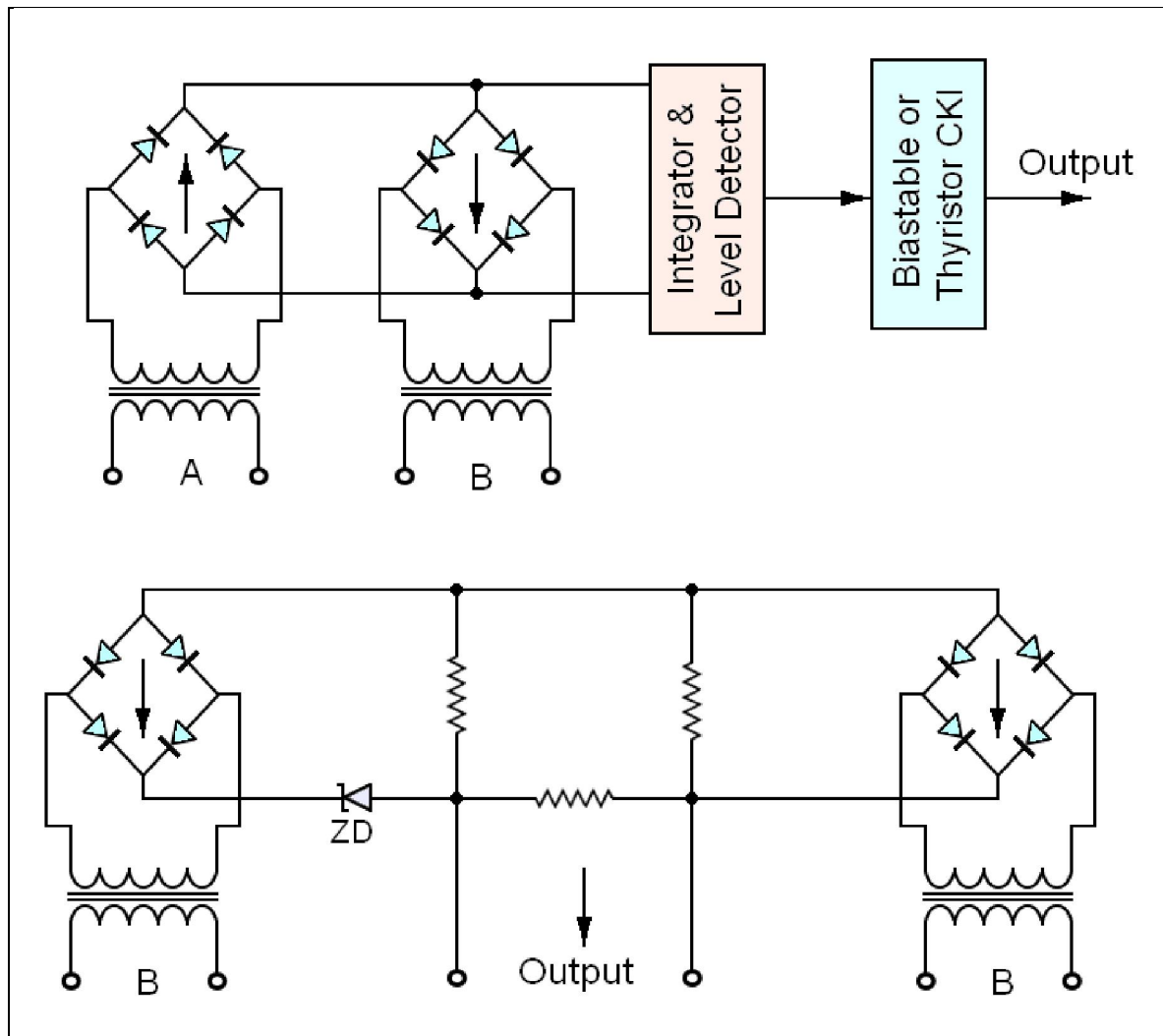


Fig 3.3-46 Basic Scheme for Rectifier Bridge Amplitude Comparator

Here the voltage outputs are utilized from the rectifier bridges in scheme (a) while current outputs are utilized in scheme (b). In both cases zener diode ZD is used for limiting the output voltage from the difference CTs. In the two schemes, the outputs from the operating and restraining circuits are the maximum values for the three phases - hence the tripping signal is automatically derived from the faulted phase/phases while the restraint output is based on the through current in the sound phase.

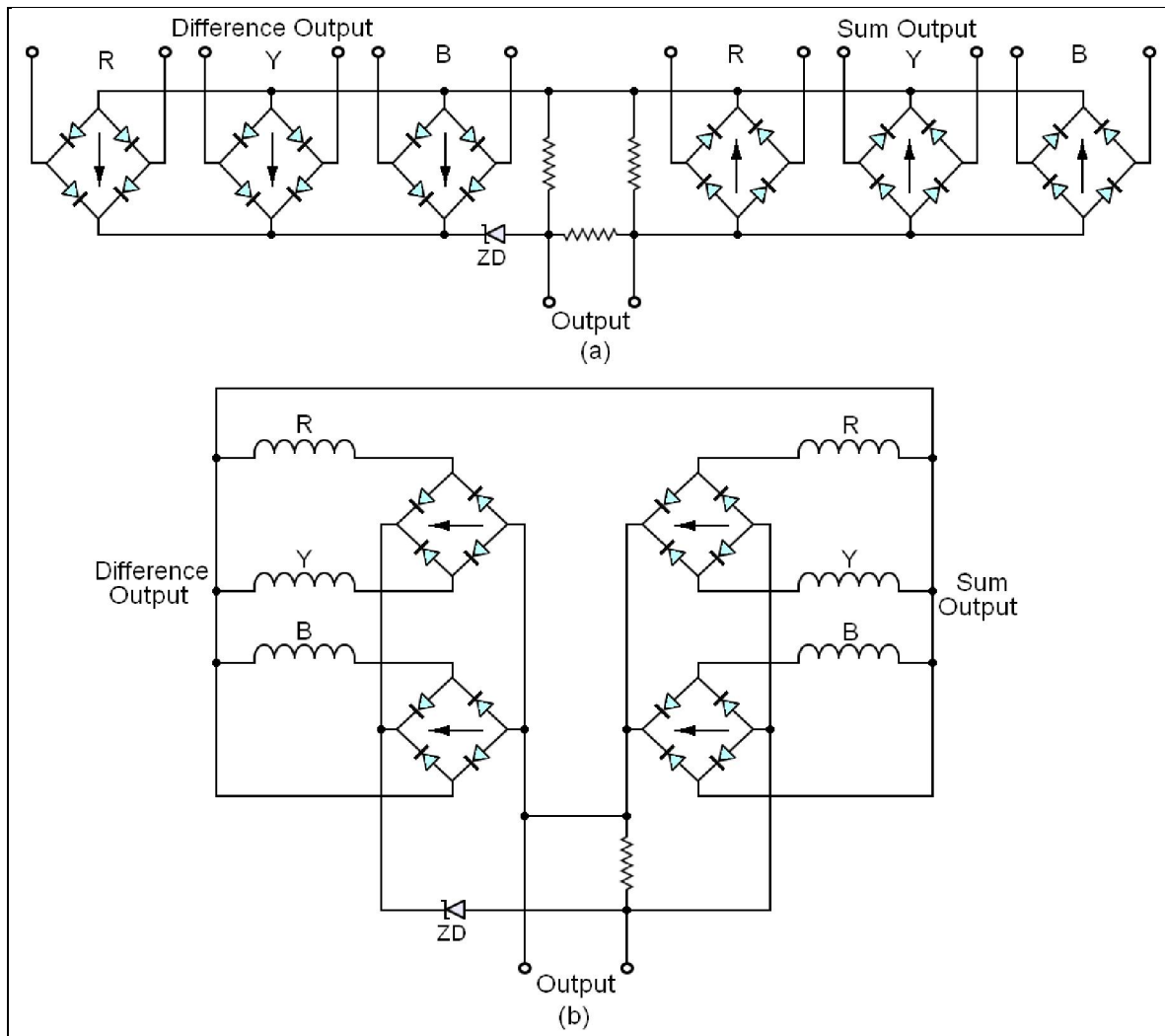


Fig 3.3-47 Polyphase Applications: (a) Voltage Comparison;And (b) Current Comparison

APPLICATIONS ON STATIC DIFFERENTIAL RELAYS TYPE MBCH 12

1. Biased Differential Protection for Transformers, Generators and Generator Transformers
2. Independent single phase relays suitable for single or three phase transformer protection schemes fast operating times, typically 10 ms to 25 ms.
3. Dual slope percentage bias restraint characteristic with adjustable basic threshold setting of 10% to 50% I_n , delectable in 10% steps.

4. High stability during through faults even under conditions of CT saturation and with up to 20% mho impedance resulting from the effects of tap changing and CT errors.
5. Magnetizing inrush restraint Over-excitation (over-fluxing) restraint
6. Up to six biased input (Fig 3.3-41).

Transformer phase group and line CT ratio correction by means of separate tapped interposing transformers where required two isolated changeover tripping contacts plus one isolated normally open latching alarm contact. The individual phase elements can be interconnected to provide six isolated change-over tripping contacts for three phase schemes Light Emitting Diode (LED) fault indication.

The type MBCH 12 Is high-speed, single phase, biased differential relay suitable for the protection of two- or three-winding power transformers, auto-transformers, or generator-transformer units.

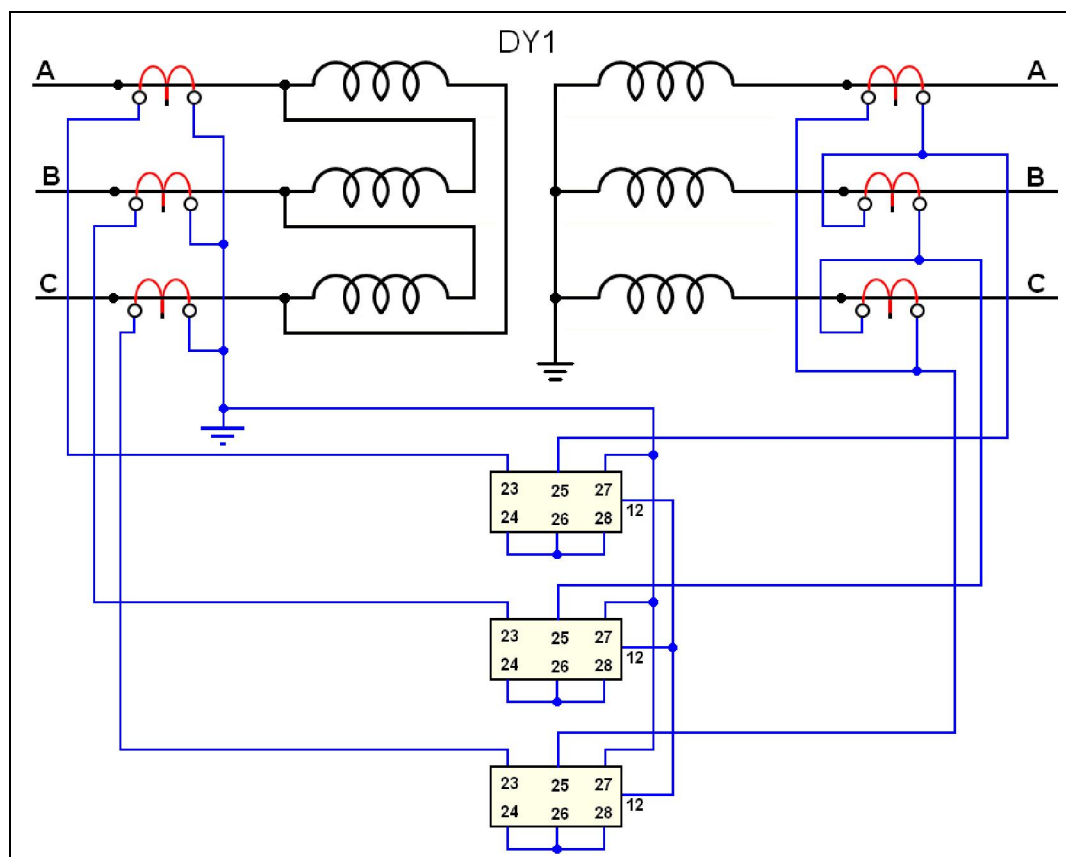


Fig 3.3-48 Application Diagram for MBCH-12

With Two-Biased Inputs

DESCRIPTION

The MBCH 12 is a range of high-speed biased differential relays suitable for protection of two winding power transformers. and Autotransformers.

The MBCH 12 may also be regarded as an alternative to the high impedance relays for the protection of reactors, motors and generators.

The relay is extremely stable during through faults and provides high speed operation on internal faults. even when energized via line current transformers of only moderate output.

Immunity to false tripping due to large inrush currents on energization of the power transformer. and during over fluxing conditions, is guaranteed without the use of harmonic filter circuits. therefore eliminating their associated delay.

A tapped interposing transformer for ratio matching of the line current transformers is available where required. The transformer taps are spaced at intervals of 4% and better, allowing matching to well within 2% in most cases.

The relay is extremely stable during through faults and provides high-speed operation on internal faults, even when energized via line current transformers of only moderate output.

Immunity to false tripping due to large inrush currents on energization of the power transformer, and also during over flux conditions, is provided by the use of a novel feature not involving harmonic filter circuits and their associated delay.

It can be beneficial to supplement the differential protection by a restricted earth fault relay, especially where the neutral point of the power transformer is earthed via a current limiting resistor.

Restricted earth fault relay may be connected into the differential circuitry, in association with a current transformer in the neutral connection of the power transformer, as indicated in Fig 3.3-42. Additional line current transformers are not required.

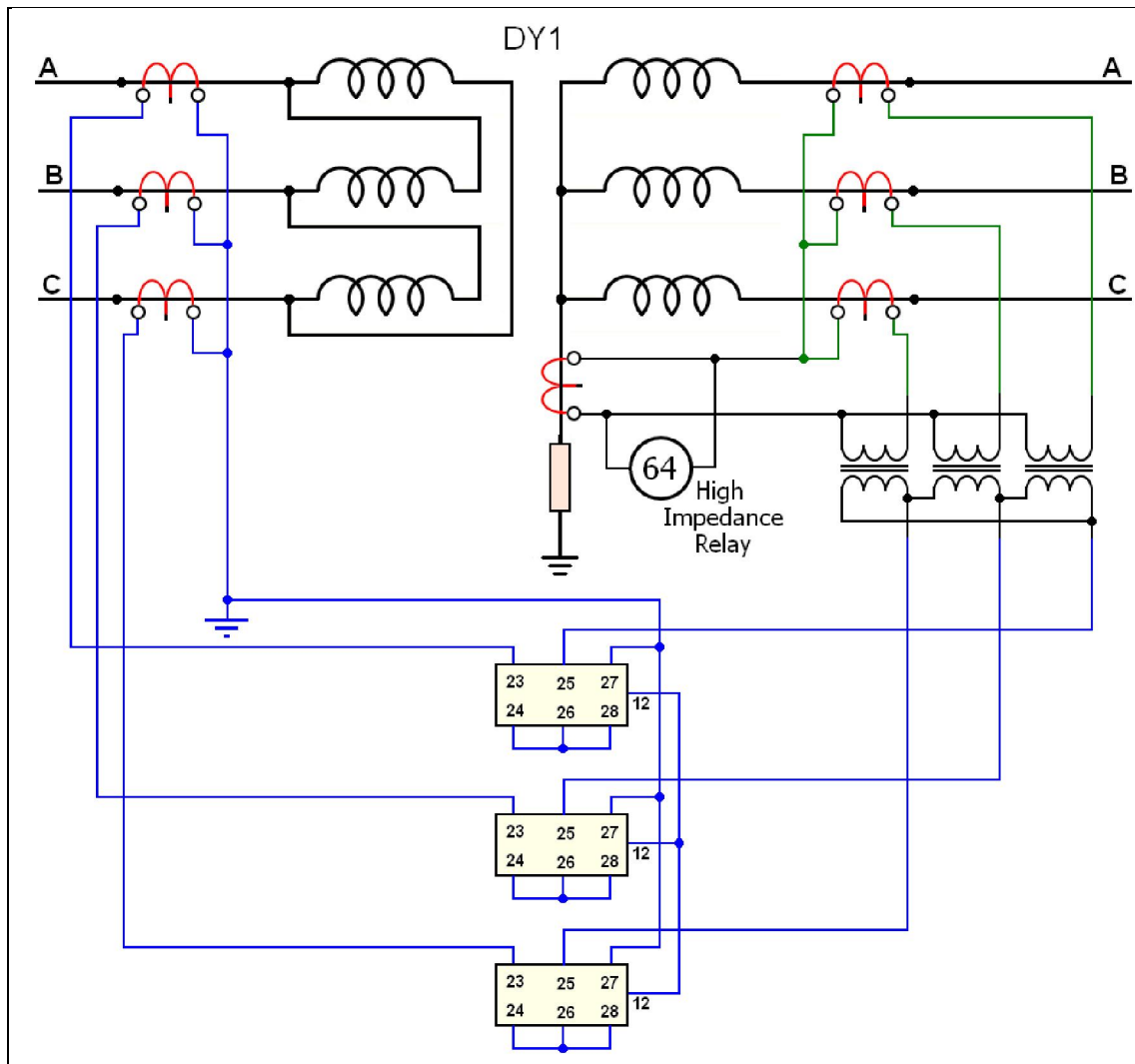


Fig 3.3-49 Typical connection diagram for MBCH-12 relays protecting DY1 transformer integrated with restricted earth-fault relays

For optimum performance, the differential scheme should be arranged so that the relay will see rated current when full load current flows in the protected circuit. This may be achieved either by appropriate choice of main line current transformers, or the use of interposing current transformers. When protecting a power transformer, the differential setting should not be less than 20% rally rated current to give stability for moderate transient over fluxing. The maximum spill current with through load current should generally be kept below 20% of the relay rated current, allowing for CT mismatch and possible tap changer operation. Where higher levels of spill current exist, the relay setting may need to be increased. A tapped interposing transformer is available for ratio matching of the main current transformers. The taps are spaced at intervals of 4%

and better, allowing matching to well within 2% in most cases. The same interposing transformers may also be used where necessary for power transformer phase shift correction. For some applications, no phase shift correction is necessary, but a zero sequence current trap is required to prevent zero sequence currents, due to external earth faults being seen by the differential relay. Two secondary windings are provided on the interposing transformer to allow the creation of an isolated delta connection for this purpose.

Each relay case incorporates a terminal block, for external connections, into which the module is plugged. Removal of the module from the case automatically causes the incoming line current transformer connections to be short circuited, followed by the open circuiting of the relay tripping circuit. Setting adjustment is by means of front plate mounted switches. Indication of relay operation is provided by an led, also mounted on the relay front plate, and which is resettable by a push button operable with the relay cover in position.

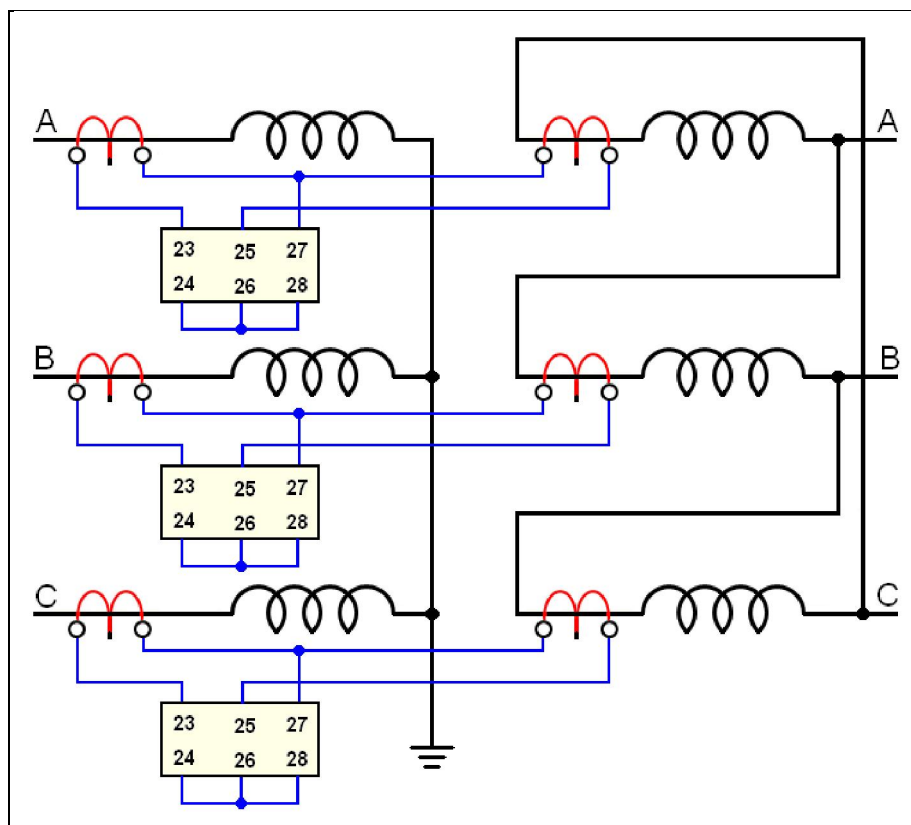


Fig 3.3-50 Typical connection diagram for MBCH relays
protecting Y D -11 transformer

The output elements consist of auxiliary attracted armature relays, the contacts of which are capable of circuit-breaker tripping. Three electrically independent contacts, comprising two self-resetting change-over contacts and one hand reset, normally open contact are provided per pole, for circuit breaker tripping and alarm purposes respectively. By interconnecting relays as shown in Fig 3.3-50, up to six self resetting change-over contacts can be provided for the three-phase tripping of up to six circuit-breakers.

FUNCTIONAL DESCRIPTION

The differential transformer protection measuring circuit is based on the well known Merz-Price circulating current principle. Fig 3.3-44 shows the relay functional block diagram.

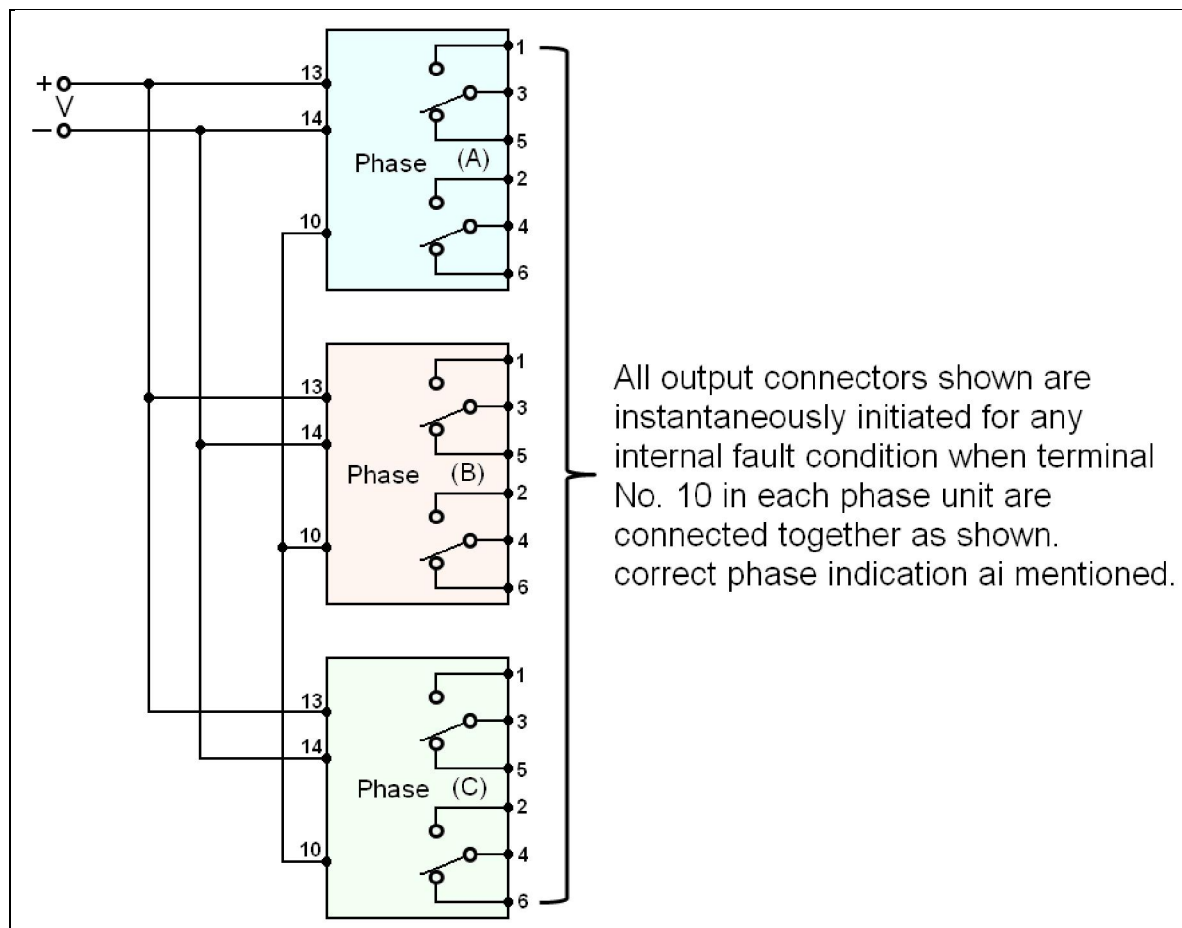


Fig 3.3-51 Connection for six change over tripping contacts for three-phase tripping of up to six circuit breakers

The outputs from each bias restraint transformer T_3 to T_5 , proportional to the appropriate primary line currents, are rectified and summed to produce a bias restraint voltage. Any resulting difference current is circulated through transformers T_1 and T_2 . The output from T_1 is rectified and combined with the bias voltage to produce a signal, which is applied to the amplitude comparator. The comparator output is in the form of pulses, which vary in width depending on the amplitude of the combined bias and difference voltages. Where the measurement of the interval between these pulses indicates less than a preset time, an internal fault is indicated and a trip signal, initiated after a short delay ($1/f$ sec), level set by the bias.

If, during the above mentioned delay, the instantaneous value of differential current falls below the threshold and remains below for longer than a further preset time, ($1/4f$ sec) as it would during transformer magnetizing inrush conditions, the trip timer is reset and operation of the relay blocked.

An unrestrained high-set circuit, which monitors the differential current, will override the amplitude comparator circuit and operate the relay output element when the difference current is above the high-set setting.

VARIABLE PERCENTAGE BIAS RESTRAINT

Even under normal operating conditions, unbalanced currents (spill current), may appear. The magnitude of the spill current depends largely on the effect of tap changing. During through faults the level of spill current will rise as a function of the fault current level. In order to avoid unwanted operation due to spill current and yet maintain high sensitivity for internal faults, when the difference current may be relatively small, the variable percentage bias restraint characteristic shown in Fig 3.3-45 is used.

The setting is defined as the minimum current, fed into one of the bias inputs and the differential circuit, to cause operation. This is adjustable between 10% and 50% of rated current. The initial bias slope is 20% from zero to rated current.

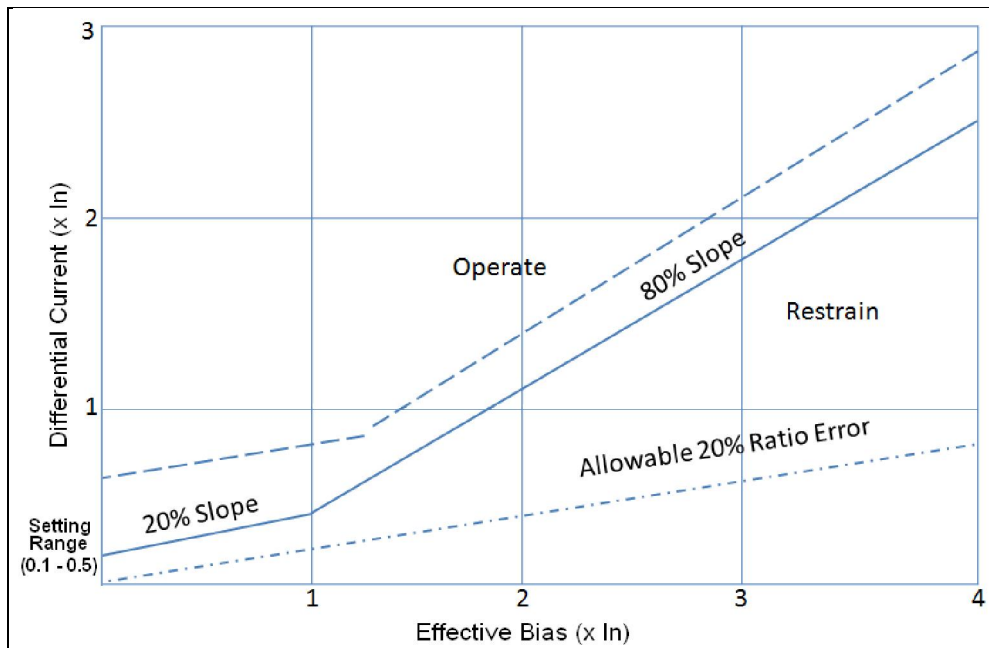


Fig 3.3-52 Typical Percentage Bias Characteristics

This ensures sensitivity to faults whilst allowing a 15% current transformer ratio mismatch when the power transformer is at the limit of its tap range, plus 5% for **CT** ratio error. Above rated current extra errors may be gradually introduced as a result of **CT** saturation. The bias slope is therefore, increased to 80% to compensate for this. At the inception of a through fault the bias is increased to more than 100%. It then falls exponentially to the steady state characteristic shown in Fig 3.3-53.

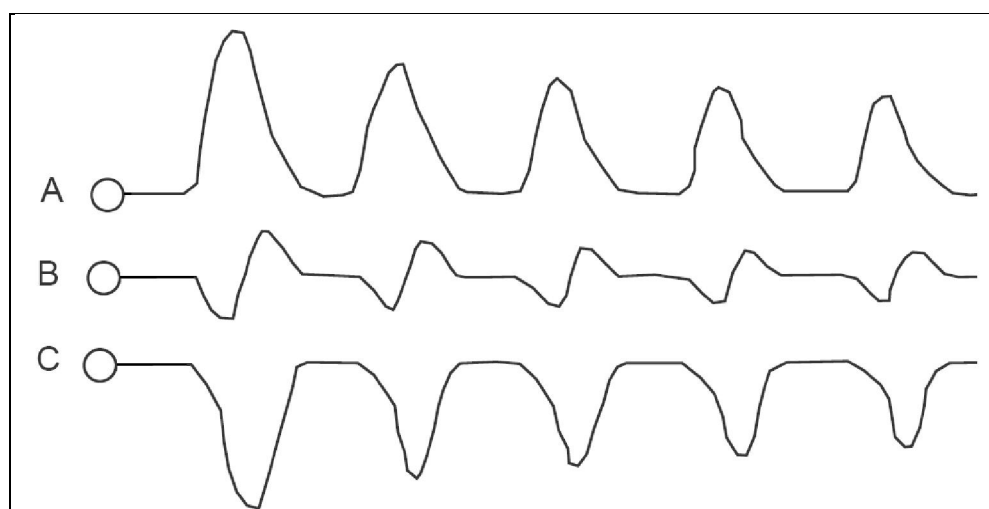


Fig 3.3-53 Typical Magnetizing Inrush Waveform

This transient bias matches the transient differential currents that result from CT saturation during through faults, so ensuring stability. However, during internal faults this transient bias is suppressed to ensure that no additional delay in operation is caused.

The transient bias circuits of the three phases are externally interconnected to ensure optimum stability of the protection during through faults.

Magnetizing inrush restraint

Particularly high inrush currents may occur on transformer energization depending on the point on wave of switching as well as on the magnetic state of the transformer core. Since the inrush current flows only in the energized winding the protection relay sees this current as difference current. To avoid unwanted tripping of the power transformer it has been customary to incorporate second harmonic restraint to block the protection relay.

Practice has shown that this technique may result in significantly slower operating times for internal faults when second harmonics are introduced into the current waveform by core saturation of line CT's. In order to overcome the problems associated with second harmonic restraint a new technique has been developed to recognize magnetizing inrush current and restrain the relay during such periods.

In practice the magnetizing inrush current waveform is characterized by a period during each cycle when little or no current flows, as shown in Figure 18. By measuring this characteristic zero period, the relay is able to determine whether the difference current is due to magnetizing inrush current or to genuine fault current and thereby inhibit operation only during the inrush condition.

This new measurement technique ensures that operating times remain unaffected even during periods of significant line CT saturation.

TRANSFORMER OVER EXCITATION

When a large section of system load is suddenly disconnected from a power transformer the voltage at the input terminals of the transformer may rise by 10-20% of

rated value giving rise to an appreciable increase in transformer steady state exciting current. The resulting exciting current may rise to a value high enough to operate the differential protection relay, since this current is seen by the input line current transformers only. Excising currents of this order are due to the input voltage exceeding the knee point voltage of the power transformer resulting in a magnetizing current wave shape as shown in Fig 3.3-54.

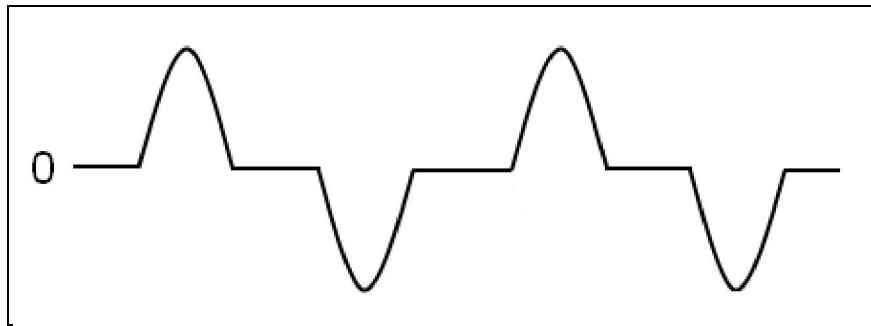


Fig 3.3-54 Magnetizing Curve with Transformer Over fluxed

By detecting the periods when the current remains close to or at zero, in a similar manner to that used to identify magnetizing inrush current, the relay is able to detect and remain insensitive to substantial over excitation current.

Where extremely large and potentially damaging over-exciting currents are possible it is recommended that an over-fluxing relay, responsive V/Hz, should be used. Such relays are designed to operate after a time delay of several seconds.

HIGH-SET

An unrestrained instantaneous high-set feature is incorporated to provide extremely fast clearance of heavy internal faults. This instantaneous feature has an auto-ranging setting, normally low at normal load throughout, but automatically rising to a higher value under heavy through fault conditions. Furthermore, immunity to magnetizing current inrush is guaranteed provided the first peak of the waveform is no greater than 12 times the rated rms. current. The problem relating to choice of a highest threshold,

which avoids tripping on magnetizing current inrush, does not, therefore, occur and no user adjustment is required.

AUXILIARY INTERPOSING TRANSFORMER

Auxiliary interposing transformers are available as triple unit assemblies as illustrated in Fig 3.3-48.

A comprehensive tap adjustment range is available as indicated by the details of turns per tap shown in Table 1.

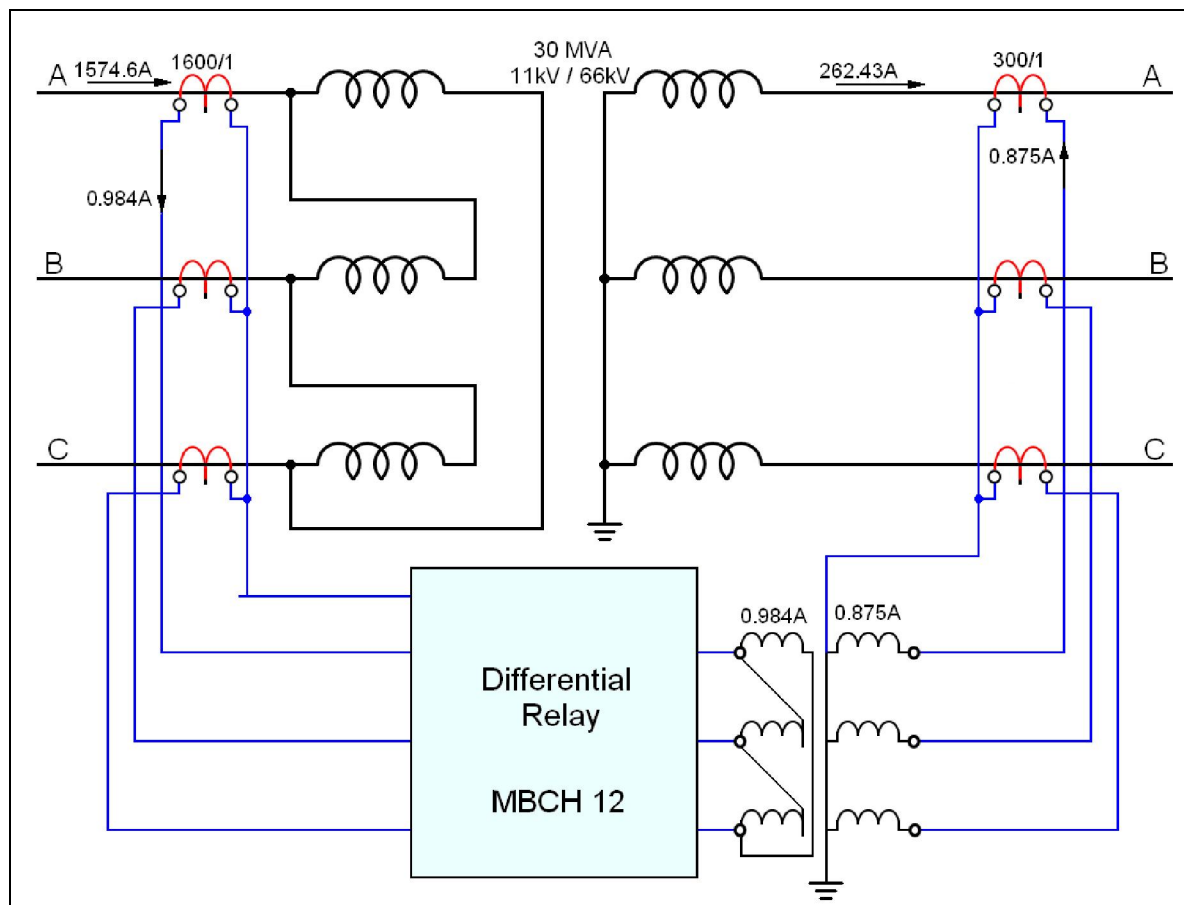


Fig 3.3-55 Two Winding Transformer with Unmatched Line Current Transformer

All line CT connections should be made to the terminal strip marked “S₁, S₂, S₃, S₄, P₁, P₂”. Selection of appropriate primary taps is made using the flexible jumper leads connected to terminals P₁ and P₂. See Fig 3.3-48. The tertiary winding S₃-S₄ must be

used in series with winding S_1 - S_2 where a delta output winding is required to ensure correct operation of the differential scheme.

HANDLING OF ELECTRONIC EQUIPMENT

A person's normal movement can easily generate electrostatic potentials of several thousand volts. Discharge of these voltages into semiconductor devices when handling electronic circuits can cause serious damage which often may not be immediately apparent but the reliability of the circuit will have been reduced.

In MBCH12 differential relays the electronic circuits are completely safe from electrostatic discharge when housed in the case. Do not expose them to the risk of damage by withdrawing modules unnecessarily.

Each module incorporates the highest practicable protection for its semiconductor devices. However if it becomes necessary to withdraw a module the following precautions should be taken to preserve the high reliability and long life for which the equipment has been designed and manufactured.

- a) Before removing a module ensures that, you are at the same electrostatic potential as the equipment by touching the case.
- b) Handle the module by its front-plate frame or edges of the printed circuit board. Avoid touching the electronic components printed circuit track or connectors.
- c) Do not pass the module to any person without first ensuring that you are both at the same electrostatic potential. Shaking hands achieves equi-potential.
- d) Place the module on an anti static surface or on a conducting surface, which is at the same potential as yourself.
- e) Store or transport the module in a conductive bag.

If you are making measurements on the internal electronic circuitry of an equipment in service it is preferable that you are earthed the case with a conductive wrist strap. Wrist straps should have a resistance to ground between $500\text{k}\Omega$ - $1\text{ Mega}\Omega$. If a wrist strap is

not available you should maintain regular contact with the case to prevent the buildup of static charge.

Instrumentation, which may be used for making measurements, should be earthed to the case whenever possible.

The type MBCH 12 relay is a high speed biased differential relay suitable for the protection of two winding transformers .

MATCHED LINE CURRENT TRANSFORMERS

For optimum performance, the differential scheme should be arranged so that the relay will see rated current when the full load current flows in the protected circuit. Where line current transformers are matched, but secondary current with full load current flowing is less than the relay rated current (as illustrated in Figure 24), the effective sensitivity of the relay will be reduced.

The transformer current is 262.4A at 6.6 kV, giving a secondary current of 4.37A from the 300/5 current transformer. For a 20% relay setting, the relay will operate when the differential exceeds “ $0.2 \times 5 =$ ” 1A

$1A = (1/4.37) \times 100\% = 22.9\%$ of transformer full load current.

Thus the effective setting is 22.9% for a relay setting of 20%.

RATIO AND PHASE MATCHING INTERPOSING TRANSFORMERS

Matching transformers are available for use in cases where the current transformers on one side of the protected transformer do not match, in current ratio or phase angle, with the current transformers on the other side of the protected transformer.

Description:

Single phase transformer 1/1A	Reference No: GJ0104 010
Single phase transformer 5/5A	Reference No: GJ0104 020
Single phase transformer 5/1A	Reference No: GJ0104 030

Three phase transformer 1/1A

Reference No: GJ0104 050

Three phase transformer 5/5A

Reference No: GJ0104 060

Three phase transformer 5/1A

Reference No: GJ0104 070

DETAILS OF MATCHING TRANSFORMERS

The winding details of the three current ratings of the matching transformers are given in the next table and in Fig 3.3-56.

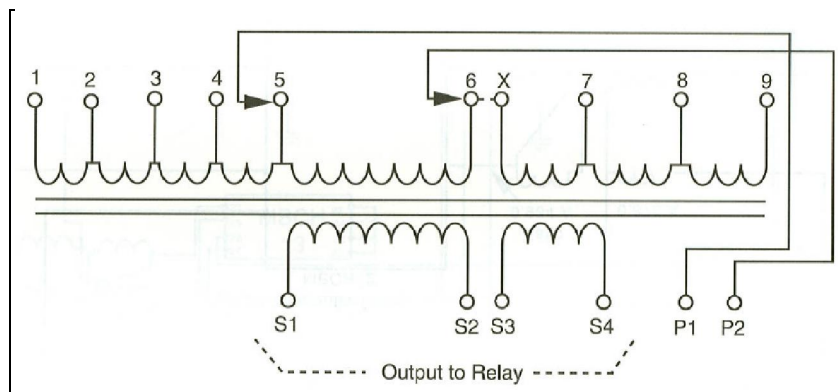


Fig 3.3-56 Disposition of winding on matching Transformer

Primary tap terminals	Number of turns Transformer rating 5/5 A
1-2	1
2-3	1
3-4	1
4-5	1
5-6	25
X 7	5
7-8	5
8-9	5
S1-S2	25
S3-S4	18

Table 3.3-2

FOR STAR-OUTPUT WINDINGS:

It is permissible to use either S1-S2 or S1-S4 (with S2-S3 linked).

Where S1-S2 alone is used, the secondary winding S3-S4 is available for formation of an isolated

FOR DELTA OUTPUT WINDINGS:

Delta connection used to prevent zero sequence currents due to external earth faults being seen by the relay.

This is for applications where phase correction is not required, but where a zero sequence trap is needed.

S 1 -S4 (with S 1 -S3 linked) must be used to obtain optimum protection performance.

APPLICATION OF MATCHING TRANSFORMER

Where the line current transformer ratios on the two sides of the protected transformer are mutually incompatible, the matching transformer may be used as in the following examples:

Example-1

SINGLE PHASE TRANSFORMER

For single phase transformer shown in Fig. 3.3-57 , Matching transformer ratio required = $3.9/4.875$. Using secondary windings S1-S2 gives 25 turns.

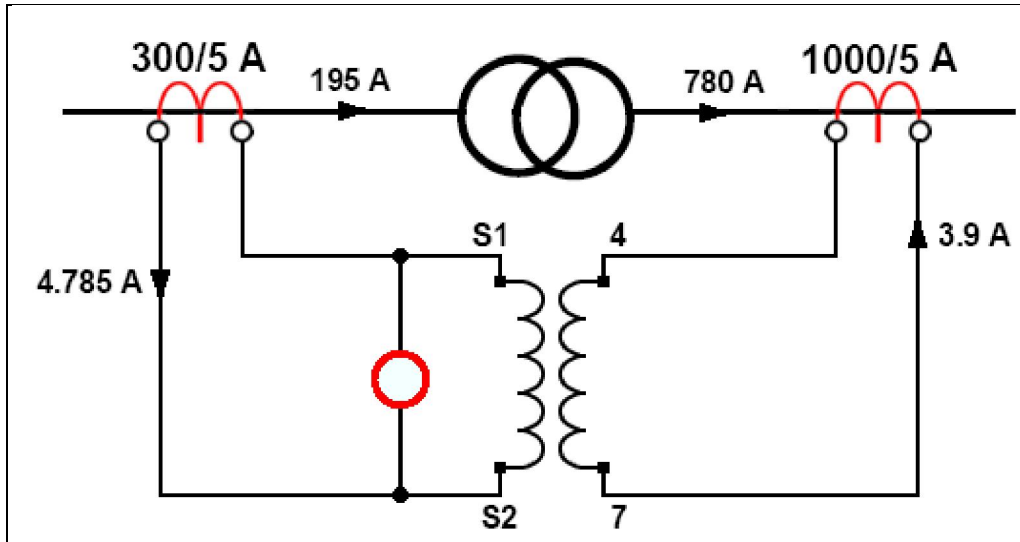


Fig 3.3-57

The number of turns required on the input (primary) winding is given by:

$$T_p = (I_s / I_p) \times T_s = 25 \times (4.785 \text{ A} / 3.9) = 31.25 = 31 \text{ turns}$$

31 turns are available between input winding terminals 4 -7 with terminals 6—X linked.

Example-2: Three Phase Transformer With Unmatched Current Transformers

Refer to Fig 3.3-48.

30 MVA transformer 11/66 kV Delta star

11 Kv Winding:

$$\text{Normal current at 11 kV} = (30 \times 10^6) / (\sqrt{3} \times 11 \times 10^3) = 1574.6 \text{ A}$$

Because the 11 kV winding is delta connected, the associated current transformers will be star connected and under rated load conditions will give the following current per pilot phase:

$$I_s = (1574.6 \times 1 \text{ A}) / 1600 = 0.984 \text{ A}$$

This current is sufficiently close to the relay rated current (1A) and furthermore requires no phase correction.

66 Kv Winding:

Normal current at 66 kV = $(30 \times 10^6) / (\sqrt{3} \times 66 \times 10^3) = 262.43$ A

Normally the current transformers associated with the star winding of the main transformer should be connected in delta to provide appropriate phase shift correction. However, since the latter in this case are connected in star the necessary phase correction may be carried out by means of a star delta connected matching transformer.

The output current, per phase pilot, of the 300/1A current transformers is given by:

$$I_s = (262.43 \times 1A) / 300 = 0.875 \text{ A}$$

This should be adjusted by the interposing transformer so that 0.984A flows into the relay.

The windings S1-S2, and S3-S4 must be used in series as output windings giving $(125 + 90) = 215$ turns. Primary turns (T_p) required, therefore are given by:

$$T_p = \frac{I_s / \sqrt{3}}{I_p} \times T_s$$

$$\text{Primary turns } (T_p) = \frac{0.984 \times 215}{\sqrt{3} \times 0.875} = 139.6$$

Say $T_p = 140$ turns

i.e. connect each phase pilot from the 300/1A current transformers to primary terminal nos. 2 and 6 (Fig 3.3-50 and Table 1). Complete connections to the interposing transformer as given in Fig 3.3-58 below:

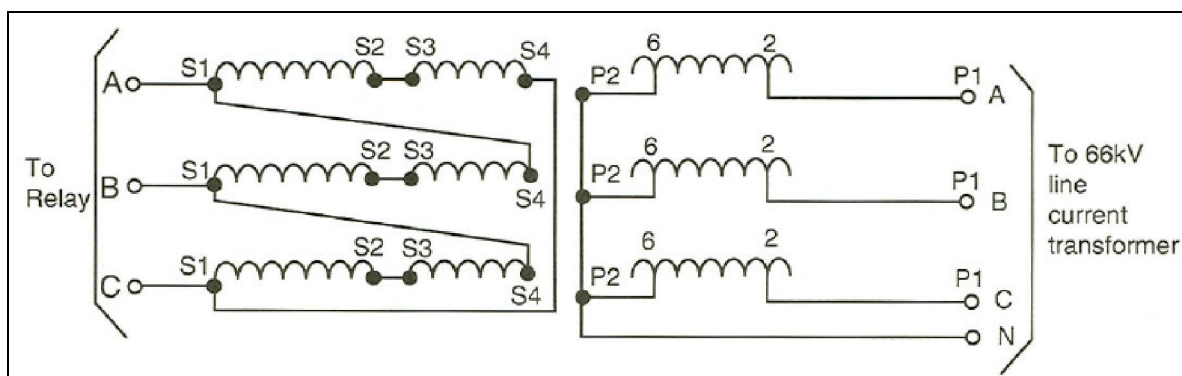


Fig 3.3-58 connections of interposing transformer

SUMMARY

- By Kirchhoff's law the vector sum of all the currents entering a circuit should be zero unless an additional current path is added
- Merits of Static Differential Protection
 - a) Relay dimensions is very small.
 - b) Absolute stability for heavy through faults.
 - c) High sensitivity for internal faults.
 - d) Extremely short tripping times regardless of magnitude of auxiliary voltage.
 - e) Accurate and Absolutely stable tripping characteristic .
 - f) Inrush-proof, even during high starting currents, inrush currents.
 - g) Low consumption (VA burden on CTs, VTs).
- Unbiased differential relay (Merz-Price type) is the simplest differential relay type in which the vector difference current gives rise to relay operation.
- Percentage bias differential relay has bias windings to provide stability on external faults.
- Normally harmonic restraint percentage differential relays for transformer protection is a static relay, this due to the fact that the summation of the through restraint and harmonic restraint has to be done by static circuits.
- The e.m. differential relays like the induction disc type are not suitable for transformer protection because it could cause false tripping due to large inrush currents on energization of the power transformer
- Transformer differential relay is provided with one or of the following:
 - a) through fault restraint,
 - b) magnetizing inrush restraint (2nd harmonic)
 - c) over-excitation restraint (5th harmonic) to counteract operation at large no-load currents caused by high voltages
- The principle of the differential protection of three winding transformer is the same as for two-winding transformers except for three-winding transformers additional components are needed. A reliable differential measurement is only

guaranteed under all possible operating conditions when a separate restraint circuit is also provided for the third winding.

- MBCH 12 static differential relays extremely stable during through faults and provides high speed operation on internal faults. even when energized via line current transformers of only moderate output.
- MBCH 12 static differential relays resist false tripping due to large inrush currents on energization of the power transformer. and during over-fluxing conditions, without the use of harmonic filter circuits.
- A tapped interposing transformer for ratio matching of the line current transformers is used when required. The transformer taps are spaced at intervals of 4% and better, allowing matching to well within 2% in most cases.
- MBCH 12 static differential relays are extremely stable during through faults and provides high speed operation on internal faults, even when energized via line current transformers of only moderate output.
- Feature of MBCH 12 static differential relays:
 1. Biased Differential Protection for Transformers, Generators and Generator Transformers
 2. Independent single phase relays suitable for single or three phase transformer protection schemes fast operating times, typically 10 ms to 25 ms.
 3. Dual slope percentage bias restraint characteristic with adjustable basic threshold setting of 10% to 50% I_n , delectable in 10% steps.
 4. High stability during through faults even under conditions of CT saturation and with up to 20% mho impedance resulting from the effects of tap changing and CT errors.
 5. High stability during magnetizing inrush restraint Over-excitation (over-fluxing) restraint
 6. Up to six biased input.
- It can be beneficial to supplement the differential protection by a restricted earth fault relay, especially where the neutral point of the power transformer is earthed via a current limiting resistor.

- Under normal operating conditions of power transformer, unbalanced currents (spill current), may appear in the operating coil of differential relays and it may cause trip during through current.
- In power transformers the magnitude of the spill current depends largely on the effect of tap changing.
- In order to avoid unwanted operation due to spill current and maintain high sensitivity for internal faults, when the difference current may be relatively small, the Variable percentage bias restraint characteristic is used
- When a large section of system load is suddenly disconnected from a power transformer the voltage at the input terminals of the transformer may rise by 10-20% of rated value giving rise to an appreciable increase in transformer steady state exciting current. The resulting exciting current may rise to a value high enough to operate the differential protection relay, since this current is seen by the input line current transformers only. Excising currents of this order are due to the input voltage exceeding the knee point voltage of the power transformer resulting in a magnetizing current wave shape.

REVIEW EXERCISE

1. As per Kirchhoff's law the vector sum of all the currents entering a circuit should be added unless an additional current path is zero. T F

Static differential protection relays are not stable during heavy through faults

T F

2. The principle of the differential protection of three winding transformer is the same as for two-winding transformers. T F

3. Give Reason: induction disc type electromagnet. differential relays are not suitable for transformer protection.

Circle the letter a, b, c or d that correctly completes the statement

4. When a large section of system load is suddenly disconnected from a power transformer the voltage at the input terminals of the transformer _____
- a) may decrease by 10-20%
 - b) will not change
 - c) may rise by 10-20%
 - d) may fall to zero
5. Under normal operating conditions of power transformer, unbalanced currents (spill current), may appear in the _____ of differential relays and it may cause trip during through current
- a) harmonic restraint unit
 - b) operating coil
 - c) restraint coil

d) instantaneous over current unit

6. The magnitude of the spill current depends largely on the effect of _____.

a) tap changing

b) transformer size

c) current transformer ratio

d) transformer ratio

7. When is the Variable percentage bias restraint characteristic differential relay used

TASK 3.3-4

TESTING STATIC DIFFERENTIAL RELAY

OBJECTIVES

Upon completion of this task, the trainee will be able to perform all type of the required tests on the Static differential relay .with a high accuracy and with a tolerance permitted in the instructional manual.

TOOLS, MATERIALS & REQUIREMENTS

- Differential relay type MBCH 12
- Test set (with timing facilities or separate timer).
- DC power supply (to suit relay auxiliary voltage 110 v).
- MMLB01 test plug MMLG Test Block is not supplied
- MMLB02 single finger test plug
- Diode rated 7A for magnetizing inrush test, if required.
- Relay technician tool kit.

SAFETY PRECAUTIONS

Check the rated auxiliary voltage on the front plate and connect a suitable smoothed dc supply or station battery supply to relay terminals 13(+ve) and 14(-ve).

NOTE:

The following test instructions are based on injecting current directly into the relay terminals, however if a MMLG test block is incorporated in the scheme, then it is more convenient to inject current into the MMLG test block..

PICKUP TEST

Relay Testing Procedures

- Connect the test set to the relay .
- Adjust the relay front panel switches to give a relay setting

$$I_s = 0.1 \times I_n$$

10% setting,

- I_n = relay rated current

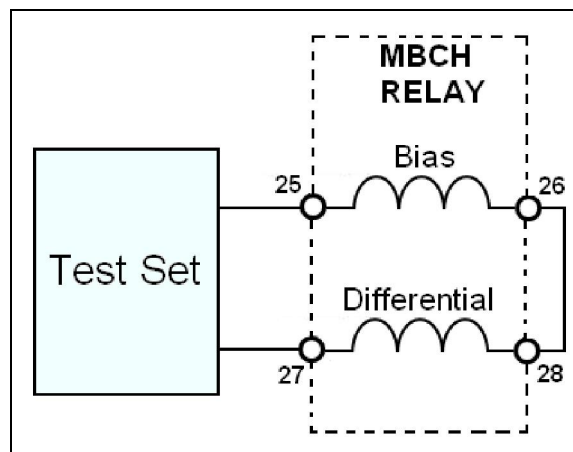


Fig. 4-1 Connection for checking relay setting

- Slowly increase the current until the relay operates, indicated by a light emitting diode (led) on the front plate.
- Note the operating (differential) current and check that this is within $\pm 10\%$ of the expected current (i.e. 0.45 to 0.55A for a 5A relay, with a 10% relay setting).
- Check that the relay trip contacts (terminals 1, 3 and 2, 4) are closed with the current above the setting, and that these contacts open as the current is removed.
- Check also that the relay alarm contacts (terminal 9, 11) are closed with the current above the setting and remain closed as the current is removed.
- Press the reset button on the relay front plate and check that the led indicator resets and that the alarm contacts open.
- Repeat the test with the relay adjusted to settings of $0.2 \times I_n$, $0.3 \times I_n$, $0.4 \times I_n$ and $0.5 \times I_n$ in turn.
- Check that the settings are within $\pm 10\%$ of the nominal value.

NOTES

- The setting may also be checked using a variable autotransformer, 0 - 100 Ohm resistor and ammeter, as an alternative to using an over current test set.
- During commissioning do not disconnect the dc auxiliary supply without first removing the ac operating current, otherwise the trip contacts on terminals 1,3 and 2,4 may remain operated. If this does occur the contacts may be reset by removing the ac operating current, and then switching on the dc auxiliary supply at rated voltage.
- Switch off the dc supply before inserting or removing modules.

OPERATING TIME

- Connect the test circuit as shown in Figure 2.
- Set the relay to $I_s = 0.2 \times I_n$ (20% setting).
- Inject $3.5 \times I_n$ and record the relay operating time.

This should be , within the range $20 \text{ ms} \pm 4 \text{ ms}$.

To check operation of the instantaneous circuit (high set), inject $4.5 \times I_n$ and record the mean relay operating time t . This should be less than 17 ms.

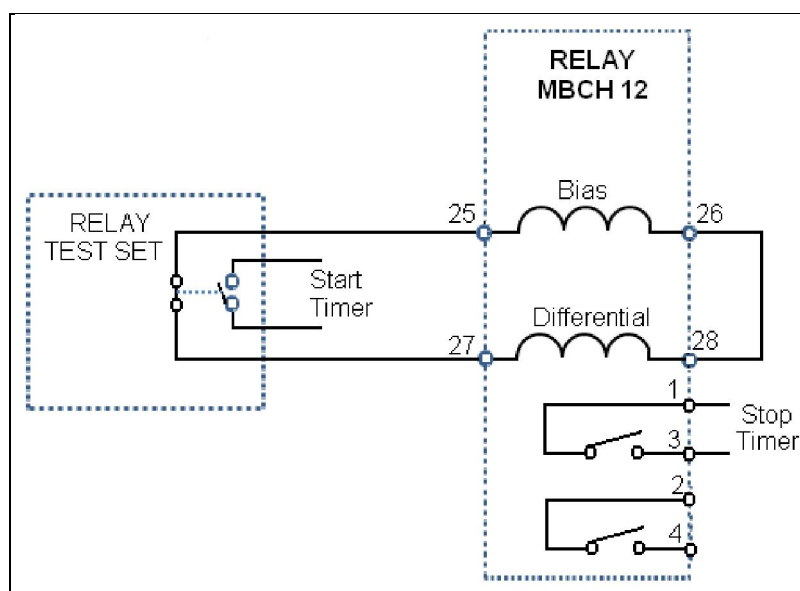


Fig. 4-2 Connection for checking relay operating time

BIAS CHECK

- Connect the test circuit as shown in Figure 3.
- Switch on the relay test set the same phase angle of both line 1 and line 2 and increase the restraining current until ammeter A1 indicates $0.6 \times I_n$.

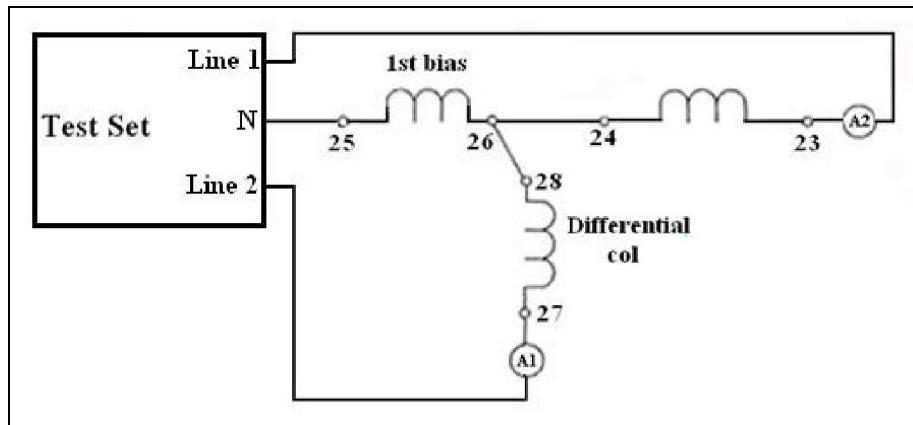


Fig. 4-3 Connection for checking relay operating time

- Slowly increase the differential current until the relay operates as indicated by the front plate led.
- Record the values of current A 1 and A2.
- Calculate the mean bias using the formula:

$$\begin{aligned} \text{Mean bias} &= A_1 + A_2/2 \text{ amps} \\ &= A_r + A_{dif}/2 = A_b + A_d/2 \end{aligned}$$

Use the bias curve Figure 4 to determine the theoretical differential current and check that the measured current A2 is within $\pm 20\%$ of this theoretical value.

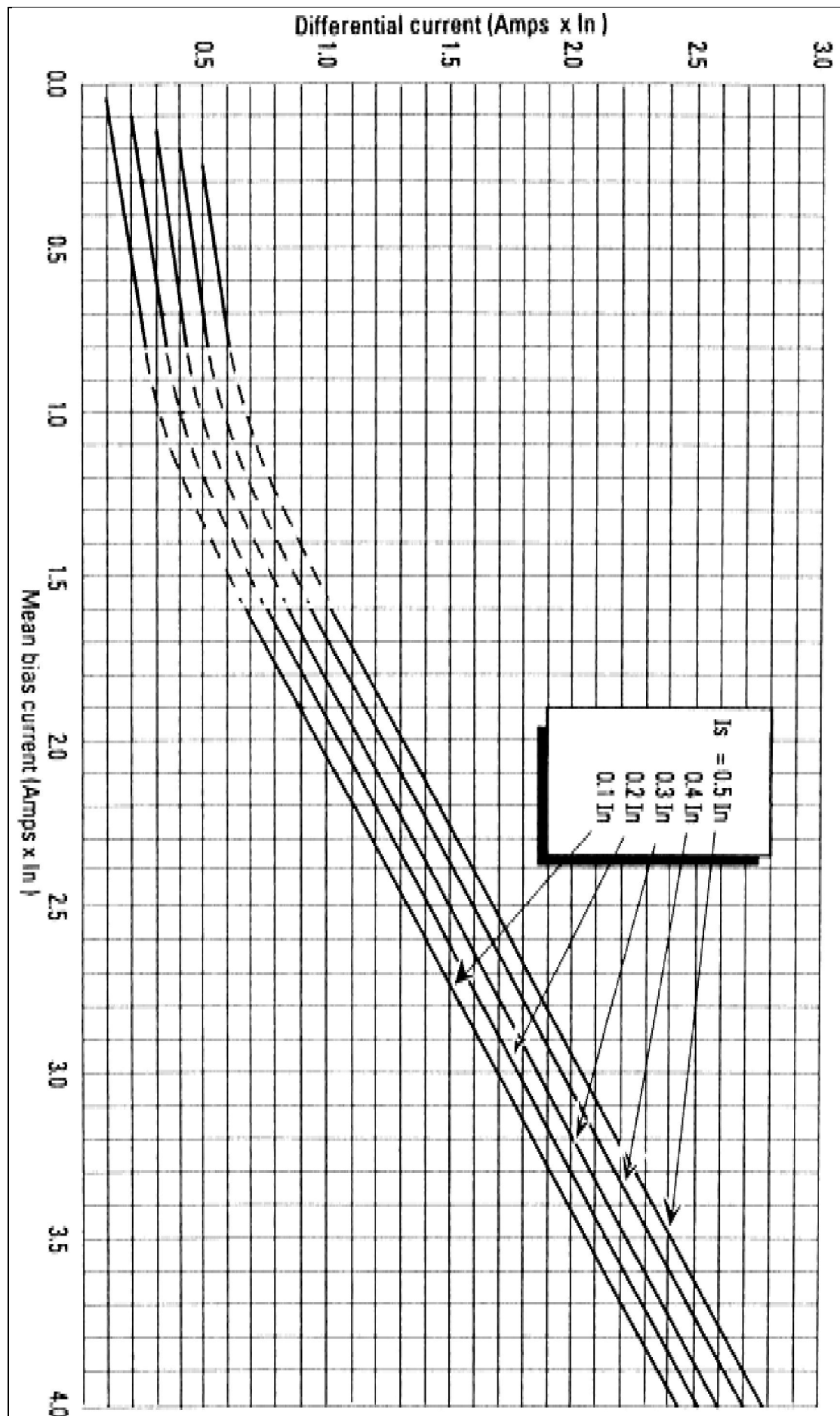


Fig. 4-4 MBCH Bias Curve

MAGNETIZING INRUSH TEST

The relay may be tested with a simulated waveform representing magnetizing inrush, by connecting a diode in series with the relay to produce a half wave rectified waveform. With reference to Figure 5, close switches S_1 and S_2 and set the current to $1 \times I_n$ (rated current).

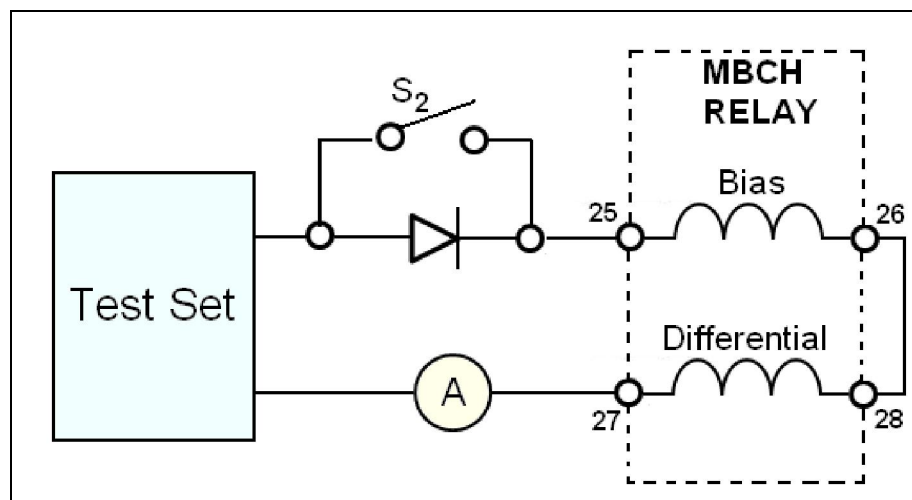


Fig. 4-5 Connection to the relay to simulate magnetizing inrush current waveform

Check that the relay operates. Open switch S_2 , close switch S_1 and check that the relay does not operate.

If it is preferred to test the relay with the magnetizing inrush current of the transformer, it is suggested that the transformer is energized ten times at full rated voltage on no load and checked that the relay does not mal operate.

BIAS INTERCONNECTION

Check that the terminals no 12 on all three phase relays are interconnected using screened leads, the screen connection being made to the negative supply (terminal no 14).

A suitable screened lead should be provided with each relay. Only two will be required for the interconnection.

CIRCUIT BREAKER TRIPPING

By interconnecting terminal no 10 of all three-phase relays, up to six self-resetting, Large over-contacts can be provided for the three phase tripping of up to six circuit breakers.

If this is required, check terminals no 10 are connected together, and check that the relay trip contacts (terminals 1,3 and 2,4) on all three phase relays close as the current injected into a single phase relay exceeds the relay setting “refer to Figure-6”.

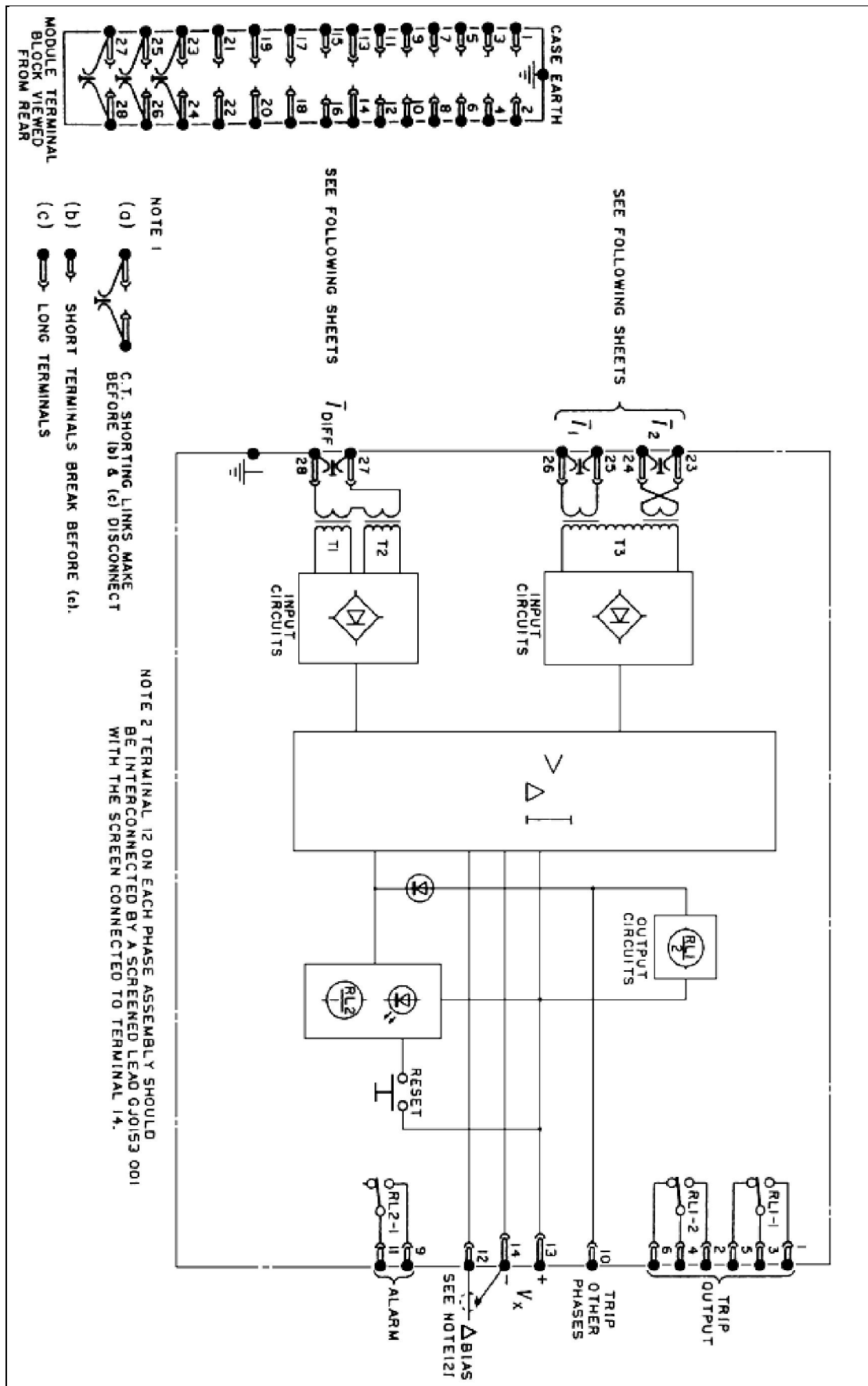


Fig. 4-6 Block diagram biased protection relay type mbch12 with two biased input

ON LOAD TESTS

The object of the on-load tests is to check that the relay is connected correctly to the system.

If the relay is protecting a transformer with no tap changer then the differential current could be less than 1% of the load current. However, if the transformer has a tap changer and the **CTs** are not matched to the transformer, then the normal differential current, with the tap changer away from the nominal position, could be as much as 20% of the load current.

Check that the load current in each bias coil is close to the value, which is expected for the particular application.

Check that the differential current under any of these conditions is within 1-20% of the load current.

The actual figure of differential - current depends upon the particular application as stated above.

Since the magnetizing current may exceed 5% of rated current for small transformers, and bearing in mind the comments of the above paragraph, it is recommended that the standard setting of the relay should be $I_s = 0.2 \times I_n$.

Check that the currents measured in the same bias or differential coils of each phase relay are similar.

**POWER SYSTEM
PROTECTION & CONTROL
STAGE 3A-PSP104
Textbook/Workbook**

JULY 2011

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